G-44

HIGHWAY RESEARCH REPORT

FULL DEPTH ASPHALT CONCRETE TEST SECTION INSTRUMENTATION

INTERIM REPORT

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16. ABSTRACT
This report contains descriptions of the asphalt concrete pavement measuring devices and the instrumentation techniques used by the California Division of Highways on three full-depth asphalt concrete pavement test sites. The pavement measuring devices included the following:

1. Gentran pressure cells and pressure gauges developed by U. C. Berkeley to determine pavement stress.
2. BLH and TML polyester strain gauges to measure strain in the pavement.
3. Iron-Constatan (Type J) thermocouples to measure pavement temperatures at different depths.
4. Schaevitz LVDT's installed in the pavement to measure deflection.

The majority of the effort was used in determining ways to adhere the strain gauges to the asphalt concrete pavement. The various techniques tried included adhering the gauges to AC specimens and then placing the specimens in the pavement, epoxying the gauges directly to the pavement, epoxying gauges to sand asphalt carriers, and epoxying gauges to polymide sheets.

The different devices and techniques are discussed in full with recommendations given as to their effectiveness and validity.

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November 1973

CA-DOT-TL-3489-1-73-39
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Mr. Robert J. Datel
State Highway Engineer

Dear Sir:

Submitted herewith is an interim research report titled:

FULL DEPTH ASPHALT CONCRETE

TEST SECTION INSTRUMENTATION

by

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ACKNOWLEDGEMENTS

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A special thanks is extended to the following Resident Engineers and their Assistants for the time and effort they spent assisting the author in placing the instruments on their projects: Indio - Carl Crawford and Jim Roy; Blythe - Chet Coolong and Vince Karliner; and Willits - Anthony Braga, Wayne Sperry and Jim Siebert.

The author further wishes to thank the Electrical Technicians, under the supervision of Mr. Albert Sequeira, who performed the instrumentation so ably and efficiently. This includes Mr. Sam Muraki, who assisted on all three projects, and Mr. William Ng, who assisted at Indio.

Mr. Gary Mann warrants a special note of appreciation for his perceptive comments and editing of this report.

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I. INTRODUCTION

The California Transportation Laboratory is currently evaluating layered elastic theory as a rational approach to the design of asphalt concrete pavements. In order to check the authenticity of the results of the layered elastic theory design method, it was necessary to install various instruments in asphalt concrete pavement to measure the dynamic response of the pavement and then compare this response with the predicted values. Three different full depth asphalt concrete pavements were instrumented to provide this data. The three projects were as follows:

(1) A full depth section of a widening portion of Interstate 10 near Indio, California,

(2) Two 1,000 foot long experimental full depth sections on Interstate 10 near Blythe, California, and

(3) A full depth widening project on U.S. 101 in the City of Willits, California.

The instruments used in these projects included: thermocouples for measuring the pavement temperatures, stress gauges and strain gauges for measuring the asphalt concrete stresses and strains, and linear variable differential transformers (LVDT's) to measure the deflection of the pavement. Also, attempts were made to measure in place moisture content with moisture blocks and with nuclear gauges.

This interim report contains a description and discussion of the different instruments and the placement techniques used in these projects. The final report will use the data obtained from the instruments described in this report, and compare these results against theoretical results as determined by the elastic layer design method.

II. CONCLUSIONS

1. The following instruments and instrumentation techniques show promise as effective ways of measuring pavement strain:

   a. Using strain gauges adhered to a sand-asphalt carrier to measure the strain on the underside of asphalt concrete pavement;

   b. Using BLH EPY-150 epoxy to adhere strain gauges to existing asphalt concrete pavement;

   c. Using strain gauged asphalt concrete specimens if proper safeguards and protections are used during their installation;

d. Epoxying strain gauges to thin sheets of Kapton, and then in turn adhering this to an existing asphalt concrete surface using a hot paving asphalt. With this procedure care must be used in areas of very hot climatic conditions.

2. The majority of the iron-constatan thermocouples (Type J) used to measure the temperature of the asphalt concrete proved to be long-lasting and are felt to be reliable.

3. The apparatus developed by the Transportation Laboratory to measure deflection of asphalt concrete pavement with LVDT's proved to be effective.

4. The use of Buoyoucos moisture blocks to measure soil moisture content was ineffective in a sandy soil.

5. The use of six-inch diameter General Transducer pressure cells to measure the stress at the interface of the asphalt concrete and base material was ineffective.

III. IMPLEMENTATION

It is believed that through the use of the different instruments and instrumentation techniques developed as a part of this project, valuable experience has been gained in instrumenting asphalt concrete pavements. These techniques can be used to test the authenticity of any proposed design procedure involving stress, strain, pavement temperature, and/or deflection. These techniques are not limited to thick lift asphalt concrete. However, the data obtained from the test sections described herein will be used to evaluate the layered elastic theory of asphalt concrete design for thick lift asphalt concrete pavement.

IV. DISCUSSION OF RESEARCH PROJECT

The principal purpose of the project is to evaluate the layered elastic theory as a rational approach to the design of asphalt concrete payments. It was believed that the best way to make such an evaluation would be to compare the "theoretical" results, as obtained by the layered elastic theory, with "actual" results as obtained with various instruments placed in the pavement. The layered elastic theory computer program to be evaluation (Chev 5-layer, with modifications made by the University of California) prints out theoretical stresses, strains and deflections at different depths and transverse distances from center of loading in the structural section. These responses are based on dynamic loading conditions in the asphalt concrete and the subgrade soil. With this capability, strain gauges, stress (pressure) gauges, and deflection measuring devices could be placed at convenient depths in the asphalt concrete pavement and the computer program written to print out the theoretical values at these known locations for the actual dynamic load conditions used.

The instrumentation portion of this project involved the following three projects:

1. Indio (11-Riv-10, 11-037514) - the widening of Interstate 10 west of Indio using full depth asphalt concrete pavement. The asphalt concrete thickness was 0.85 ft. with a 0.25 ft. aggregate base working table under the asphalt concrete.

2. Blythe (11-Riv-10, 11-094714) - two 1,000 ft. full depth asphalt concrete test sections were instrumented on the Interstate 10 Blythe bypass. Test section "A" consists of 0.85 ft. of asphalt concrete placed directly on the subgrade soil, while test section "B" contains 1.50 ft. of asphalt concrete placed directly on the subgrade.

3. Willits (01-Men-101, 01-111804) - U.S. 101 through the City of Willits was widened and resurfaced, with a portion of the widening being full depth asphalt concrete. The thickness of the pavement was 1.00 ft., and it was placed directly on the subgrade soil.

Originally, the Indio project was to be instrumented only with thermocouples and moisture blocks. However, a literature search revealed that very few researchers had instrumented asphalt concrete pavements (1,2). It was therefore decided to use Indio as an experimental testing project. At Indio, various techniques and pavement measurement devices developed by ourselves and other researchers were tried to determine their feasibility for the other two projects. The different placement techniques and pavement response measurement instruments used for each of the three projects are discussed below.

V. DISCUSSION OF INSTRUMENTS AND INSTALLATION - INDIO

Gypsum Moisture Blocks:

The original work plan called for the installation of gypsum moisture blocks to determine soil suction and the moisture content of the soil for the Indio project. Gypsum moisture blocks were purchased as well as a Buoyoucos Moisture meter for the calibration of the moisture blocks. Two pressure pots and two ceramic plates (15 bar pressure range) were borrowed from the University of California for use in this calibration.

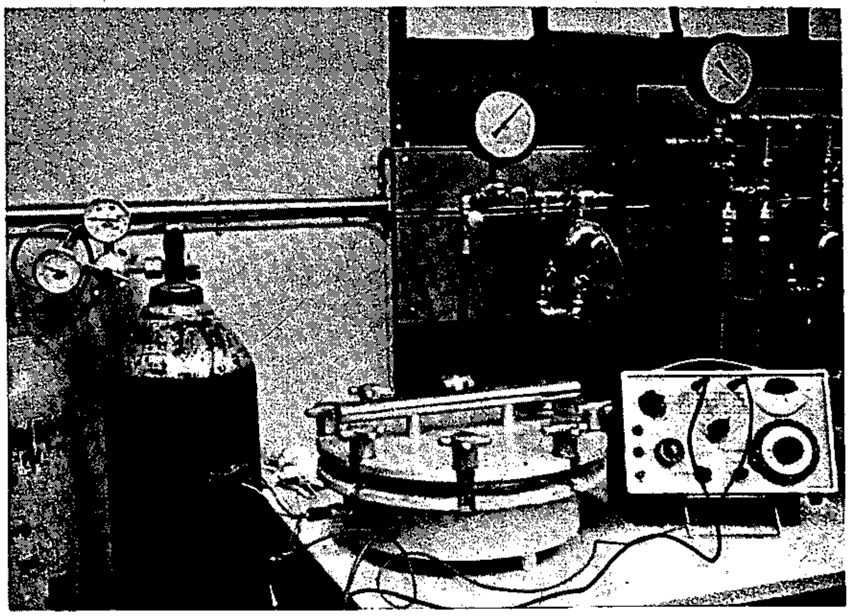


Figure 1 Equipment used in calibration of gypsum moisture blocks.

The calibration process consisted of immersing 15 moisture blocks in distilled water and monitoring the electrical resistance of the blocks to determine when the resistance would yield a stable reading for saturation conditions. During this period it was determined that the electrical resistance could not be monitored by a conventional direct-current ohmeter since direct current induced hydrolytic interference. Four alternating current impedance meters were considered. They were as follows: 1) A universal resistance bridge - this would have been ideal from an accuracy viewpoint but the only such bridge available to us was a bulky, slow-reading device. Purchase of a new quick-reading bridge was considered prohibitively expensive; 2) A resistivity meter called a "Vibroground" was tried but proved excessively bulky and time-consuming; 3) A quick-reading compact meter, the Fischer M-scope was tried and found to be useful for low resistance readings associated with saturated conditions; and 4) A Bouyoucos moisture meter - for higher resistance readings (over 500 ohms) and all pressure cell calibration work; this meter was judged most appropriate by virtue of its compactness and range. The latter two meters were calibrated and found to be imprecise with as much as 10 percent deviation from the standard. Thus the precaution of using the same meter for all readings in a given series of calibration measurements was thereafter observed.

The behavior of the gypsum blocks in distilled water was monitored. It was found that the blocks stabilized at resistances around 280 ohms after soaking 30 or more days. Figure 2 shows a typical calibration that was obtained for the moisture blocks. Also, research literature was searched for a methodical calibration procedure. The most comprehensive study of gypsum blocks was found in G. D. Aitchison's edition of Moisture Equilibria and Moisture Changes in Soils Beneath Covered Areas (3). This study was one of the basic sources cited by University of California researchers and others (4,5).

Some features of gypsum block behavior as described in Aitchison's work have been compared with the findings of the Transportation Laboratory and with the published findings of the University of California as presented below.

1. Time Response: Aitchison indicated that a 30-40 day time lag should be expected for resistance values to stabilize. This was confirmed by the Transportation Laboratory since not only blocks immersed in water for the first time but also blocks which had been wetted, dried, and rewetted showed the same time delay characteristics. This behavior differed from that observed by the U.C. researchers who reported stabilization intervals of 4 days or less (4).

2. Temperature Sensitivity: The sensitivity checked reasonably well with the theoretical temperature sensitivity predicted by Slater and Bryant (6) in the equation

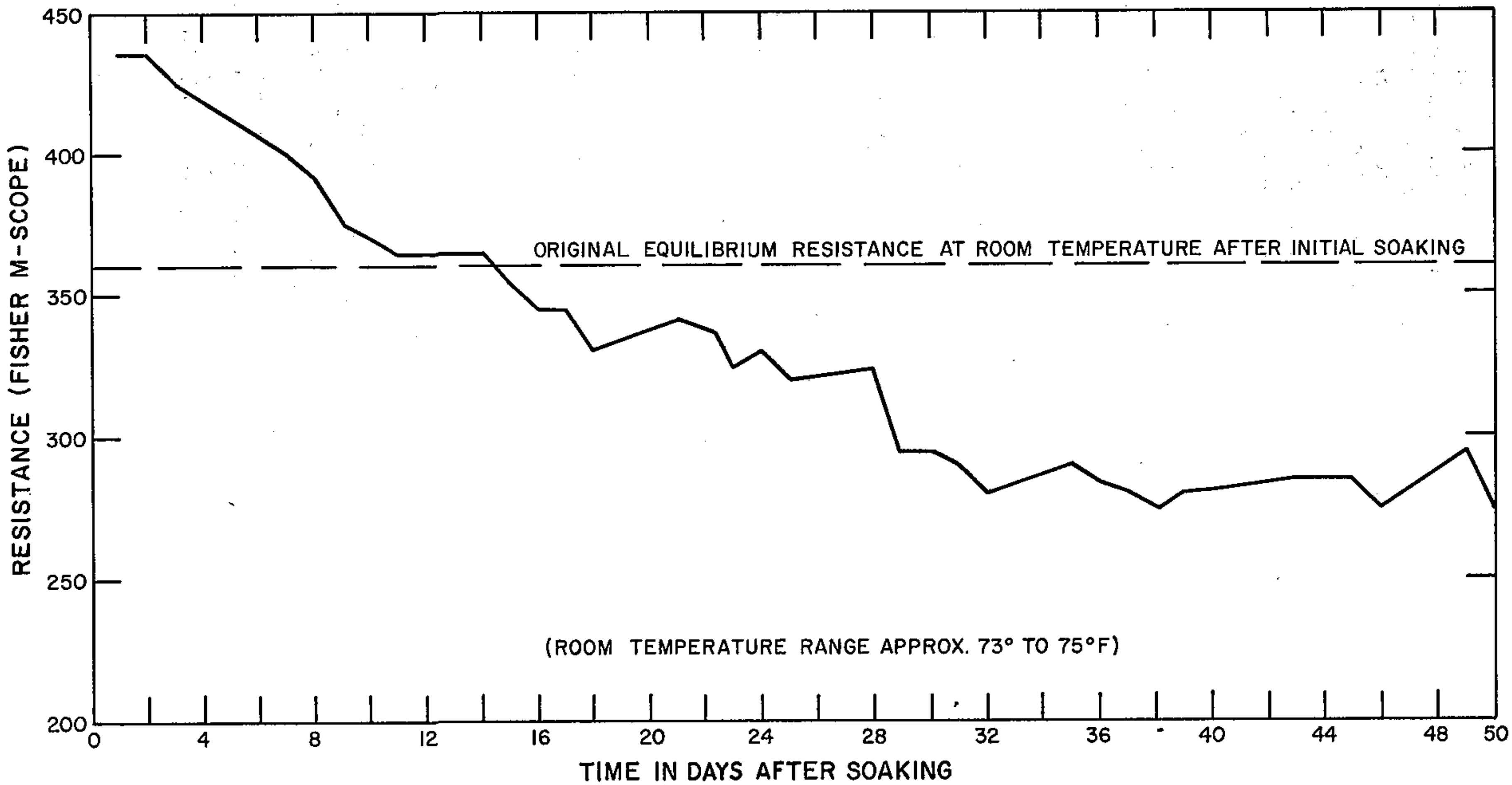
$$Rc = Ro^{1+.002(To-Tc)}$$

The blocks monitored by the Transportation Laboratory showed, for example, a decrease from 270 ohms (Rc) at 73°F (Tc) to 260 ohms (Ro) at 75°F (To), while if the formula is used Rc would equal 266 ohms.

Aitchison and the U. C. Researchers also accepted the above equation in their studies (3,4).

3. Soil Salinity: Since it is well known that the soluble salt content of a soil will affect its resistivity, Aitchison presented tentative correction factors for different values of this important parameter. The U. C. investigators, on the other hand, attempted to hold this variable constant for any given set of experiments. The latter approach was used for the Indio project in that soil from the actual subgrade was used for all lab experiments.

Figure 2



RESISTANCE BEHAVIOR OF BLOCK #1 IN WATER AFTER SOAKING, DRYING, AND RESOAKING

4. Hysteresis: The U. C. researchers concluded that hysteresis was time related. They found that calibration curves shifted in time to become meaningless after two years or less. Aitchison saw hysteresis as related to the wetting or drying history of the gypsum block and felt that calibration was possible for both wetting and drying cycles. However, Transportation Laboratory tests revealed that one cycle of soaking, drying, and resoaking decreased the block resistance from about 360 ohms to near 300 ohms in distilled water at room temperature. Calibrations so obtained would only be useful in field situations where the investigator knew whether the subgrade was in a wetting or a drying cycle and how many cycles had previously occurred.

5. Operating Range: Both Aitchison and the U. C. researchers thought that the operating range of the gypsum blocks with regard to changes in moisture conditions in pavement subgrades to be adequate. However, Transportation Laboratory tests revealed that the blocks were accurate only when water contents below 3 percent were present in the Indio subgrade soil. Since in place water contents as high as from 4 to 6 percent were expected, the blocks offered a limited operating range for this granular subgrade and their use was abandoned.

If the use of gypsum moisture blocks is pursued further, the following areas would have to be investigated in more detail:

1. Temperature sensitivity should be checked through a broader range so as to check the applicability of Slater and Bryant's equation to expected subgrade temperature conditions.

2. If soil salinity is to be assumed constant, then the reasonableness of the assumption should be verified by checking field conditions when the blocks are placed _in situ_.

3. Since hysteresis appears as both a function of time, and as a function of the number of wetting and drying cycles of the soil, it should be studied over as long a period as possible to obtain adequate calibration curves.

4. Efforts should be made to increase the range of moisture contents within which the blocks are accurate either by improving the calibration technique or by limiting the use of gypsum blocks to particular types of soils.

Because of the above problems associated with the moisture blocks, it was decided to abandon their use in determining soil suction, and instead attempt to determine the moisture content of the soil with the use of a nuclear gauge (7).

Moisture Determinations - Nuclear Gauge:

After our experiences with the gypsum moisture blocks we decided to try to determine the subgrade moisture using a nuclear depth probe. In order to get the depth measurements, a metal tube to house the depth gauge had to be installed in the subgrade soil (Figure 3).

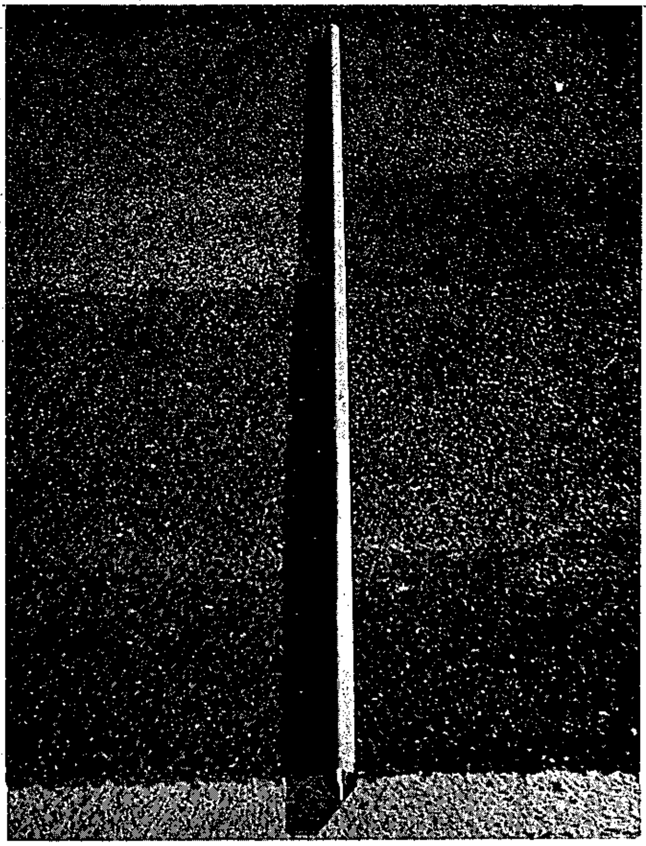


Figure 3 Metal tube used for nuclear depth readings.

This tube was a 10 foot long, 1-5/8 inch I.D. thinwall metal tube with a 0.035 inch wall. A metal tip was welded to one end of the tube for use in installation. A 4-inch core was taken out of the AC pavement and then a 2-inch diameter soil sampler hole was drilled to about 5 feet beneath the pavement. Tubes of the soil were taken and used for moisture and density determinations. The metal tube was then driven the rest of the way using the drop hammer on a standard drill rig. A casing with a removeable cap was then epoxied to the AC, to allow access to the tube.

The nuclear depth gauge used was a Model P-20 depth density probe by Nuclear-Chicago. The scaler used was a Nuclear-Chicago Model 2800 requiring either battery or AC power. The probe cord was marked off in one foot increments, with readings made at each increment. The soil samples taken originally were used to calibrate our first set of nuclear readings. It was felt that by using this method we could detect changes in moisture content with depth at different times during the year. Figure 4 shows an operator making moisture depth readings using the Nuclear-Chicago gauge.

Figure 4 Operator using nuclear depth gauge.

The Nuclear-Chicago gauge was not satisfactory as it was unable to stand the high ambient temperatures at Indio during the time of testing and, as a consequence, gave erratic and meaningless results.

<u>"Stress" Gauge - Gentran Pressure Cells</u>:

For the Indio project, Gentran pressure cells were selected to measure stress at the interface of the aggregate base and the subgrade soil. Although originally built to determine stress at the interface between concrete culverts and backfill, it was felt that they might provide a method of measuring this stress.

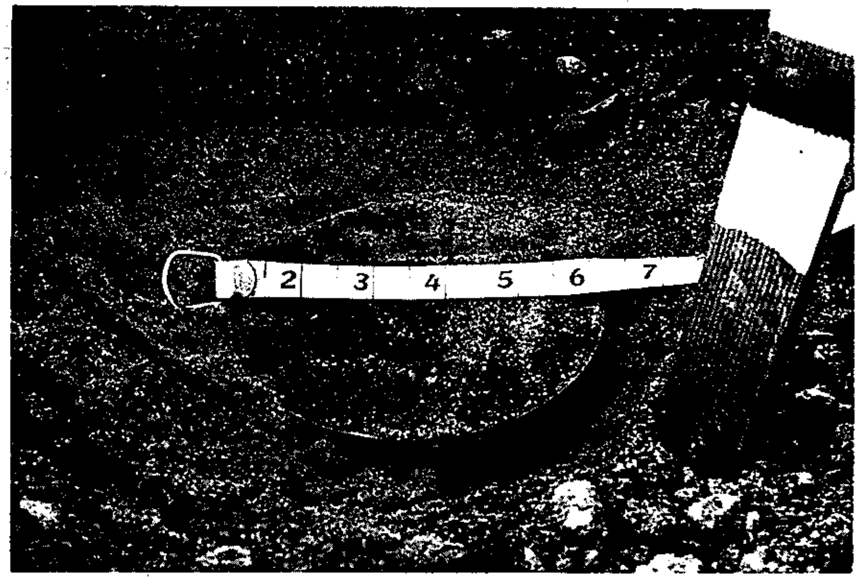


Figure 5 Gentran Pressure Cell

The Gentran pressure cells used at Indio were Model GT-621 soil pressure cells manufactured by General Transducer Co. of Sunnyvale, California. Their design load range was from 0 to 100 psi. The Gentran pressure cell (Fig. 5) is a hydroelectrical device consisting of a hydraulic load sensing unit and an electrical pressure transducer. The load sensing unit consists of two machined steel plate diaphragms welded together so as to form a central cavity. The cavity contains a lightweight machine oil which transmits applied pressure to a pressure transducer diaphragm. The cells were calibrated using a hydrostatic method and also by placing the cell at the interface of soil and asphalt concrete in a large pressure chamber. The latter calibration curve was to be used to determine the in situ pressures. No problems were encountered in calibrating these pressure cells.

In conversations with the manufacturers of the cells, it was revealed that the transducers were highly sensitive to any temperatures above 150°F. Therefore, to correct for this the transducers (which are located normal to the cell - in Figure 5 the transducer is placed down) were coated with a waterproofing epoxy agent so that during placement in the basement material, a mass of wet soil could be placed around the transducers to provide the needed temperature protection. The three inches of base material over the cell also provided protection from the heat of the asphalt concrete during placing. The three gauges were checked after the third lift (March 1971) and all three gauges were found to be operable. However, during the testing of the completed full depth pavement in June 1971, it was found that none of the three pressure cells were operable. Two of the cells were shorted out, while the third cell gave no reading, even when the test truck was placed directly over it. The most probable cause for the short-circuits in the cells was moisture entering the transducer through cracks formed in the epoxy. For the third cell, a slow leak of the hydraulic fluid could have occurred which would worsen with time and prevent a measurement from being recorded on the pressure cell indicator.

Strain Gauges:

The largest amount of instrumentation effort involved placing strain-gauges in the pavement. The question of what size strain gauge to use was widely discussed prior to installing any strain gauges. The problem is two-fold; the gauge must be long enough so that it will not be placed entirely on one piece of aggregate in the mix, yet short enough so that it will not rest on two pieces of aggregate and "bridge" the AC mix. Both of the above cases will, of course, give erroneous results, so it is imperative to use a gauge length of an intermediate size. In conversation with other researchers who had attempted to strain gauge asphalt concrete pavements, a gauge length between 1/2 and 1-1/2 inches in effective length was deemed most appropriate.

Therefore, strain gauges with an effective length of 3/4 inch were used almost exclusively. At Indio BLH SR-4 AB-3-S6 strain-gauges were used. Their effective gauge length was 3/4 inch. On one lift, for comparative purposes, a BLH type DLB-MK-354A-S6 gauge with an effective length of 1/4 inch was used.

In placing the strain gauges in the AC, two different methods of placement were employed. These methods were 1) epoxying the strain gauges to prefabricated AC specimens (bars or briquettes), of approximately one-half the design lift thickness, and 2) epoxying the gauges directly to the AC pavement itself. The prefabricated bars and briquettes were fabricated with a mix that was the same as that used in the Indio pavement. The method of epoxying the strain gauges to the prefabricated bars (and to the existing pavement) was as follows: First, a thin layer of BLH EPY-150 epoxy was placed on the surface, with its dimensions being about twice that of the strain gauge used. Care was taken not to place the epoxy directly over a piece of coarse aggregate in the asphalt concrete specimens. Then the epoxy was heated to accelerate its cure. Once the epoxy had set, it was sanded with emery cloth until it was an extremely thin layer with about the same surface profile as the AC specimens. The strain gauge was then attached to the epoxy layer with the same type epoxy, and the curing process repeated. The leads of the strain gauge were connected to the lead wire, and the entire assembly then covered with an in-house formulated thiokol epoxy mixture which cures to a pliable plastic state. This coating was used as a waterproofing agent and also as mechanical protection for the gauges. An additional waterproofing agent of Herecol Company's RC-9 synthetic, liquid, self-vulcanizing rubber was then applied to the entire assembly to complete the process.

The field method of placing the bars and briquettes in the pavement was as follows: A heavy coat of spray paint was applied to the underlying surface (pavement or aggregate base) at the desired location with approximately the same dimensions as the bar or briquette (Fig. 6). Immediately after the paver placed the asphalt concrete over this area and prior to the rolling, the AC was removed until the spray paint was exposed (Fig. 7). A trench for the lead wires leading through the AC was dug, the bars or briquettes put in position, the lead wires placed in the trench, and the AC placed back over the bars and wires. On the thinner lifts, it was found that by using a hand roller before the breakdown roller went over the site, more strain gauges were operable after the lift was completed (Fig. 8). By using the hand roller, the AC above the strain gauges appeared to be better able to support the roller and, therefore, transmitted less pressure directly to the gauge and the lead wires.

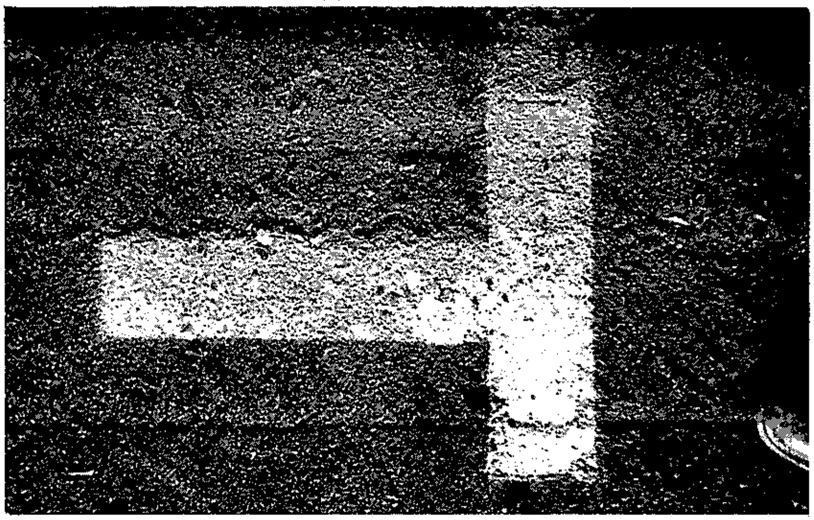


Figure 6 "T" painted on surface used to locate strain gauge bars.

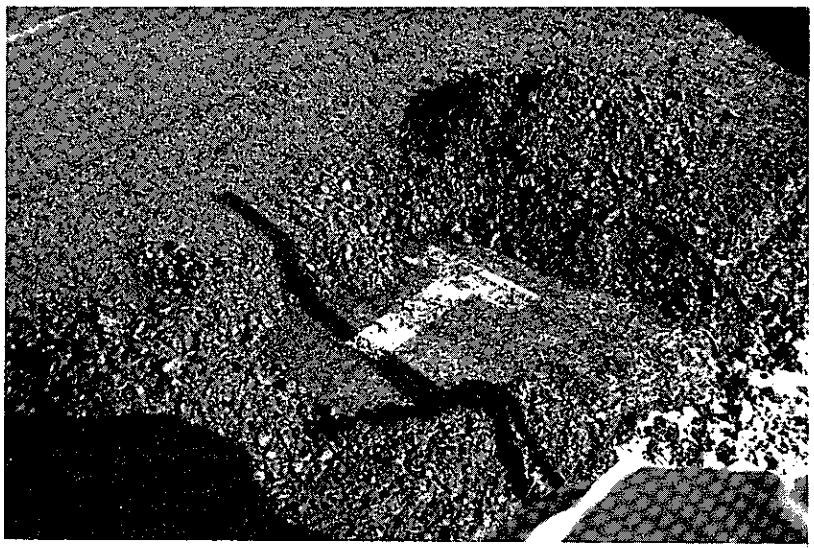


Figure 7 "T" showing intended location of strain gauged specimens after paving.

Figure 8 Hand rolling over gauges prior to breakdown rolling.

When epoxying the gauges directly to the AC pavement, the procedure employed was exactly the same as the laboratory method of epoxying the gauges to the AC specimens. On warm days it was found that the heat of the pavement was sufficient to cure the epoxy in a short period of time (Fig. 9). The leads of the strain gauges were then connected to the lead wires (Figs. 10 and 11) and covered with the in-house formulated thiokol epoxy mixture and Herecol Company's RC-9 synthetic, liquid, self-vulcanizing rubber (Fig. 12). These coatings were used as waterproofing agents and for mechanical protection of the gauges.

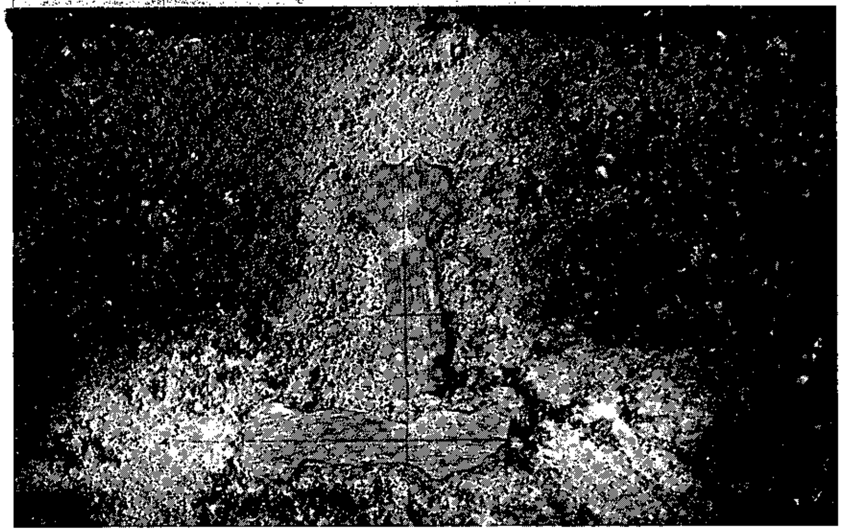


Figure 9 Epoxy for base of strain gauges after sanding.

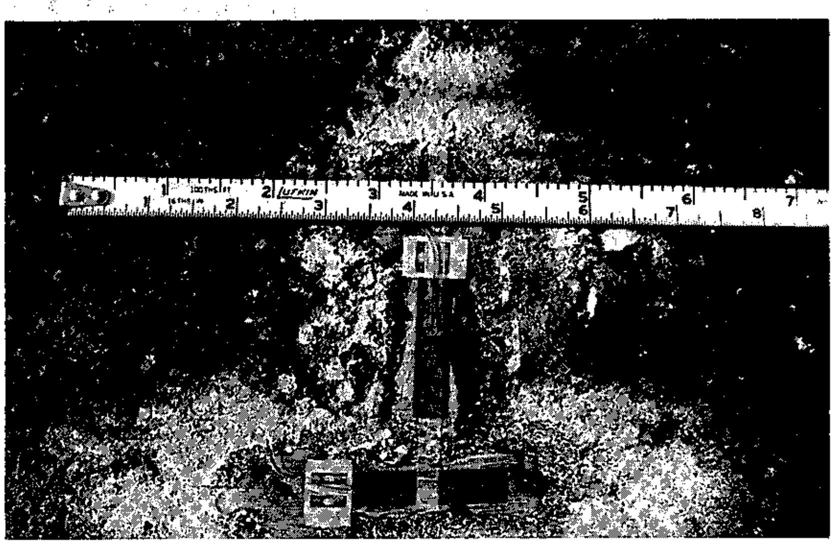


Figure 10 3/4-inch strain gauges adhered to epoxy filler 0.15 ft. on center.

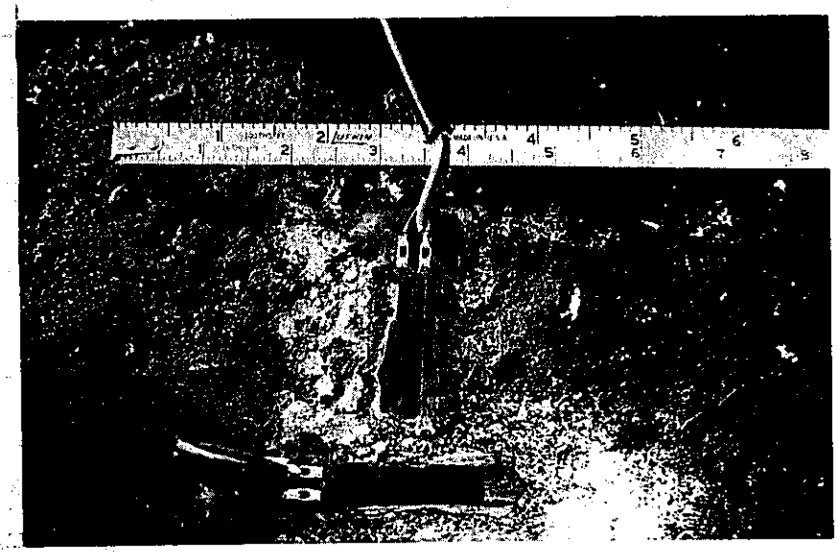


Figure 11 Completed strain gauges epoxied to surface.

Figure 12 Strain gauges with waterproofing RC-9 applied.

Starting in January, 1971, the first lift of AC was placed (0.30 ft.). In all, a total of 5 lifts were placed at Indio, including the open-graded surface layer, for a total depth of 1.0 ft. In each of these lifts except the second lift, longitudinal and transverse strain gauges were placed. A total of 44 strain gauges were placed in the pavement at Indio, with 23 being operational during the final testing. (See Fig. 13 for diagram of location of all working gauges.)

In the first (lowest) AC lift, all of the strain gauges were epoxied onto prefabricated AC specimens. Two bars or two briquettes were placed at each site, one placed longitudinally to traffic and the other transverse, (Figs. 14 and 15). A total of 12 gauges were used in the first lift. Of these 12, only one of the gauges placed on the bottom of the bars was operational after the pavement was compacted, while four of the top gauges were operational. It is believed that the bottom gauges came in contact with rocks in the aggregate base layer and, as the roller passed over them, they were crushed. As stated before, no instruments were placed in the second lift. This lift was placed four days after the first due to an unannounced change in the contractors paving schedule.

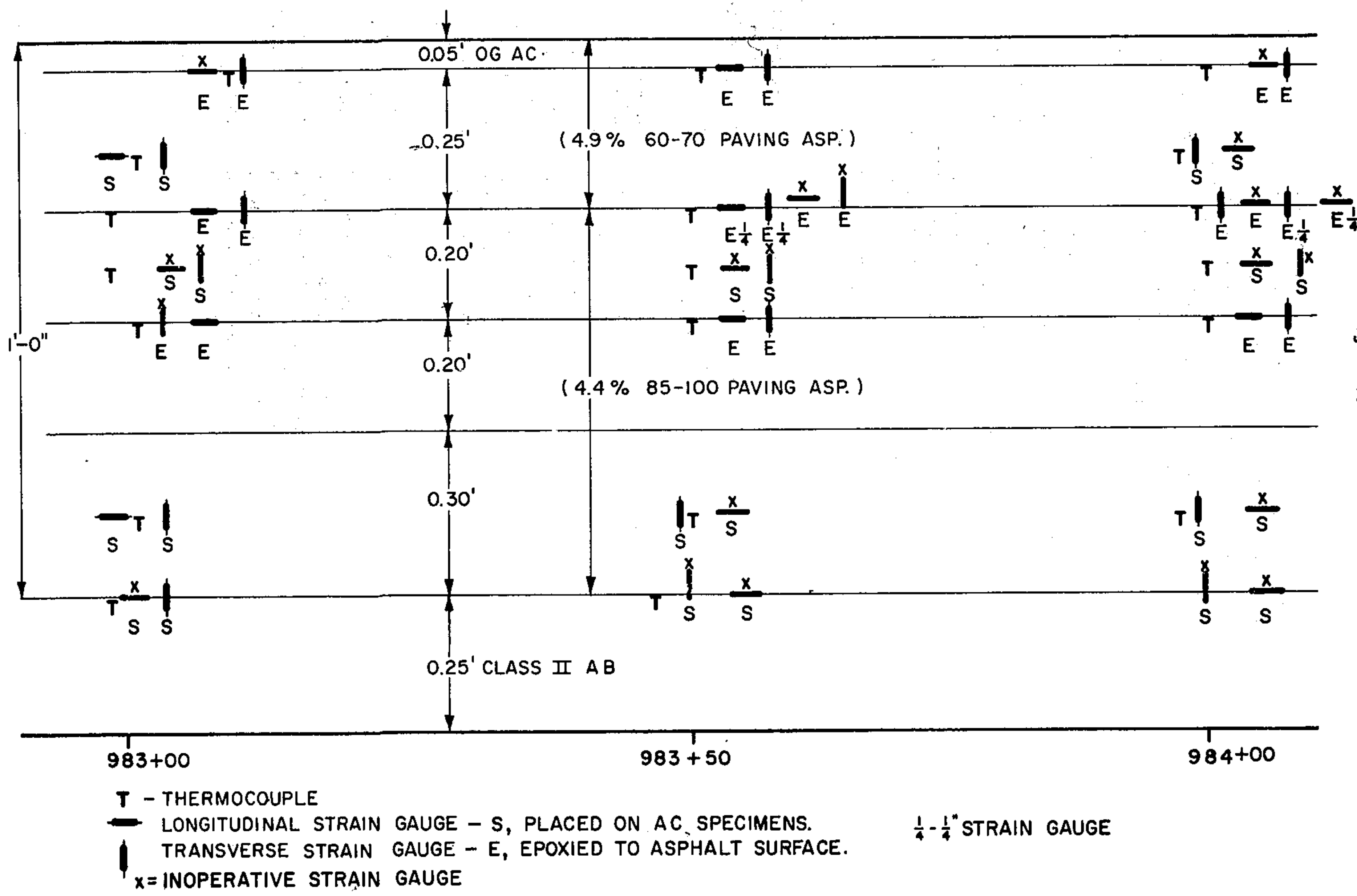
In the third lift both methods of placement were used. However, as the lift thickness was originally planned for 0.15 ft., the AC specimens were 0.078 ft. thick and strain gauges were epoxied only on the top of the specimens to get the strain readings midway between the top and the bottom of the lift.

A total of six strain gauges were epoxied directly on the top of the lower lift while six gauges were epoxied to specimens and placed in the lift. After the rolling operation was completed, the gauges were checked and it was found that five out of six gauges epoxied to the pavement surface were still operational but none of the six gauges epoxied to the AC specimens were working. In retrospect, it is believed that this lift was too thin to use the bars as this left less than an inch of AC to distribute the load of the rollers to the gauges.

In lift four (0.25 ft.), prefabricated bars were made approximately 0.10 ft. thick. Also, in this lift two sets of smaller strain gauges (BLH Type DLB-MK-354A-S6) were used for comparative purposes to see if the shorter gauges would give different readings at the same location. These smaller gauges were 1/4 inch in length as contrasted to the 3/4 inch length of the other gauges. In this lift, four short and six regular (3/4 inch) gauges were epoxied to the top of the existing

Figure 13

INDIO
INSTRUMENTATION



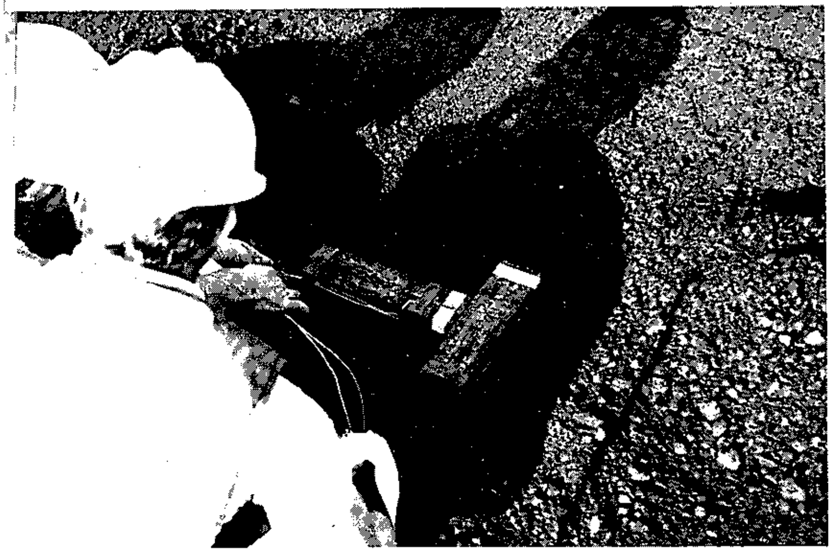


Figure 14 Bars with strain gauges and thermocouples.

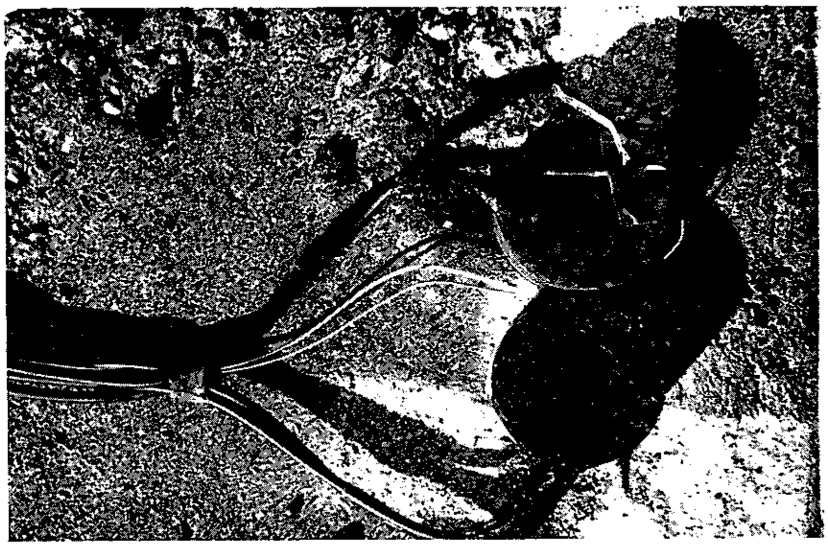


Figure 15 Briquettes with strain gauges and thermocouple.

pavement, while four bars were placed in the pavement. The lead wires from the epoxied strain gauges were stapled to the existing pavement to keep them below the paver's screed. After the new pavement was compacted, it was found that three out of the four shorter epoxied gauges, three out of the six regular epoxied gauges, and three out of the four gauges on the bars were operable. Two of the epoxied gauges were destroyed when an asphalt concrete haul truck applied its brakes directly over the lead wires and ripped them off the strain gauges.

Before the last layer of open-graded AC (.05 ft. thick) was placed, the last set of strain gauges was installed. In this lift, six regular size strain gauges were epoxied to the top surface of the previous lift. This time, grooves approximately 1/4 inch wide by 1 inch deep were cut in the underlying pavement. The lead wires were placed in these groves and covered with epoxy sealant (State Specification 701-80-36) as added protection. The strain gauges were given an operational check prior to the actual testing of the sites, and it was found that four out of the six gauges were operable. The two gauges that failed were both placed longitudinally to traffic. Again, it is highly probable that the roller may have strained these gauges beyond their capabilities.

The overall performance of the strain gauges and their placing techniques at Indio can be summarized as follows:

1. The technique of epoxying strain gauges to the underside of AC specimens to determine the strain on the underside of the AC pavement (very bottom) was found to be inadequate. A new method will have to be found to measure this strain.

2. The technique of epoxying strain gauges to the top of AC bars or briquetts was determined to be adequate if proper safeguards and protection are used during their installation and subsequent compaction of the lift being instrumented.

3. The method of epoxying strain gauges to an existing layer of AC pavement was found to be reliable. A disadvantage of this method is that it would be time consuming in cool climates.

Pavement Temperature Thermocouples:

Iron-constatan (Type J) thermocouples were installed at different depths in the AC pavement at the same time the strain gauges were placed. A total of 17 thermocouples worked during the testing period out of the 20 that were installed. The instrument used to record the temperatures was a Honeywell temperature recorder capable of simultaneously recording measurements from 20 thermocouples. Figure 16 shows the Honeywell recorder installed in a controller cabinet.

Figure 16 Thermocouple Read Out Device.

A difficulty noted with this particular Honeywell model was that it took a large amount of time to reduce the data from the machine chart to a useable form.

The thermocouples at Indio were monitored for about a nine month period and all 17 thermocouples continued to give readings throughout this period.

Deflection Measurement - LVDT

In order to measure the deflection of AC pavements at different depths in the AC, a device was developed for use in conjunction with Linear Variable Differential Transformers (LVDT's). In our tests, the LVDT's used were manufactured by Schaevitz Engineering Co. and were Model 033SS-L. The range of this particular model is 0.033 inches before it starts losing its linearity.

At each test station, LVDT's were placed at the approximate mid depth of each lift (total four) in the AC pavement. To place the LVDT's, 3-inch diameter holes were drilled completely through the AC pavement (the cores were saved and later used for extraction tests). A 5 foot long by 1 inch diameter steel buffer pipe, with one end rounded for easier driving, was then driven into the basement soil using a two-headed driving rod (Fig. 17). The driving rod was built so that it fitted snugly into the buffer pipe up to the driving rod's lower head. The pipe was then driven into the soil by pounding on the upper head of the driving rod with a pneumatic hammer or by using the drop hammer of a drill rig (Fig. 18). The driving rod was then withdrawn and a 1/4 inch by 7 foot steel pipe, with one end threaded, was driven through the center of the 1 inch casing until the threaded end of the pipe was at the approximate desired height in the AC (this also firmly embedded the other end into the soil beneath the casing). To drive the 1/4 inch pipe, a pipe sleeve or coupler was placed on the threaded end of the pipe with a driving pipe projecting out the other end of the sleeve. The driving pipe was then driven to the desired height. Figure 19 shows the device made to hold the LVDT's in place. The basic intent of the device was to attach the LVDT to the AC at the desired depth and thus measure the movement of this AC relative to the reference rod (1/4-inch pipe). As can be seen from Figure 19, the LVDT core was attached to a threaded rod which fit through a threaded hole in a pipe cap which in turn was attached to the 1/4-inch pipe. The 1-inch diameter by 5 foot water pipe acted as a buffer so that the 1/4-inch pipe did not come into contact with the basement soil for the first 5 feet beneath the bottom of the AC. It was assumed that most of the movement in the basement soil caused by traffic loads would be dampened within this distance. Therefore, the 1/4-inch pipe acted as a relatively immobile reference rod. The LVDT itself was held firmly within the LVDT holder by means of the Allen set screws. The LVDT holder was imbedded in the AC at the desired depth by simply turning the cam on top of the holder, which drove the sharpened wheels into the AC. This procedure left the LVDT and LVDT holder embedded in the AC at the desired depth. Therefore, as a truck of known rear axle load passed over the hole, the LVDT deflected with the AC while the LVDT core was relatively unaffected by the load.

To insure that the holes kept their original shape, 3-inch diameter cylinders equivalent in length to the design thickness of the AC pavement were placed in the holes between tests. A jacking device was made so that these cylinders could be extracted from the holes after a period of several months to allow re-testing of the site. Figures 20 and 21 show the LVDT holders prior to and after placement.

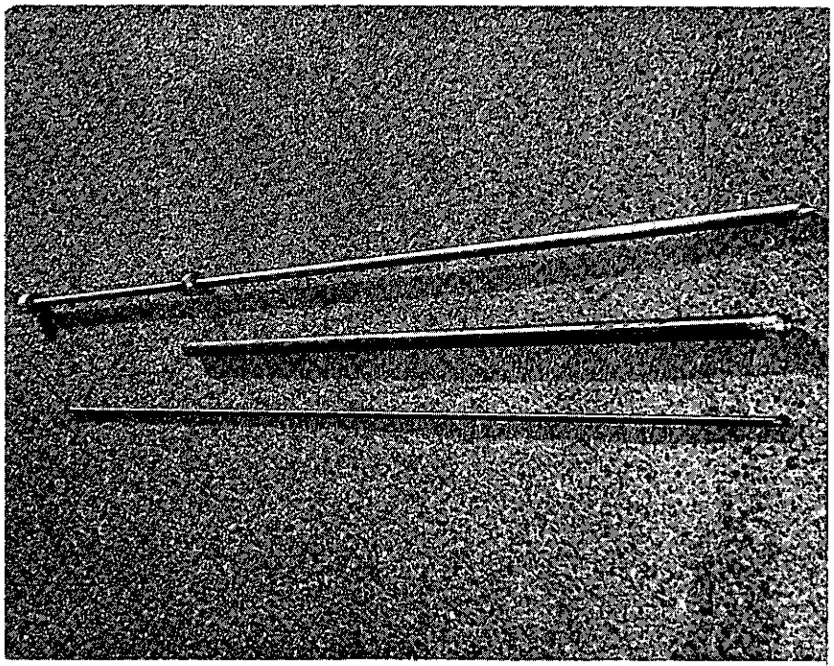


Figure 17 From the top: two-headed driving pipe used to drive buffer pipe into soil; buffer pipe; LVDT reference rod with one end threaded.

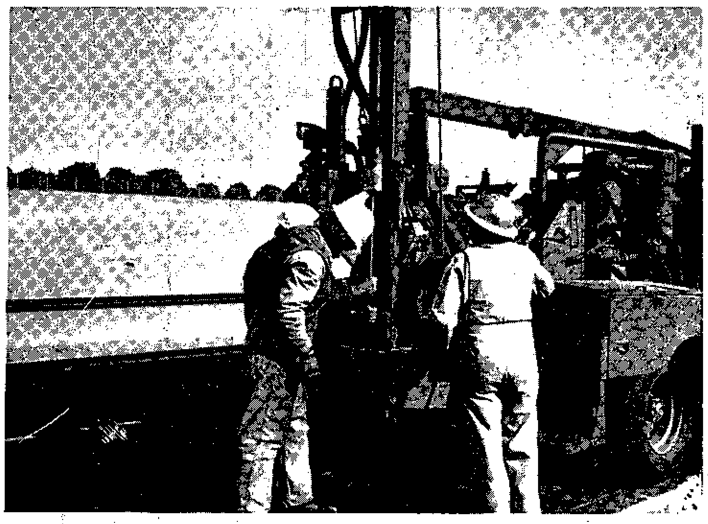
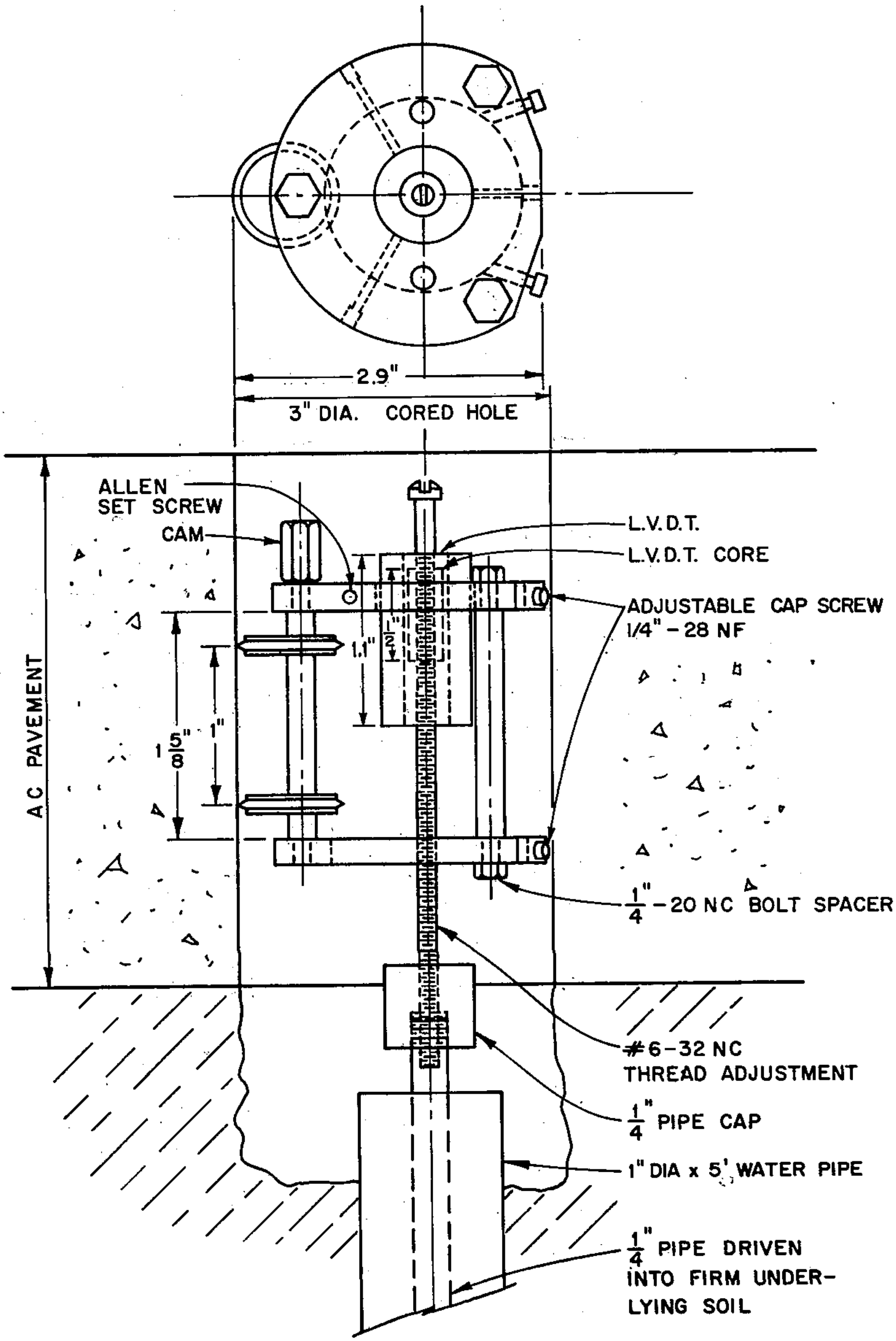


Figure 18 Driving the buffer pipe using the two-headed driving pipe and a drill rig.

Figure 19

AC DEFLECTION MEASURING DEVICE



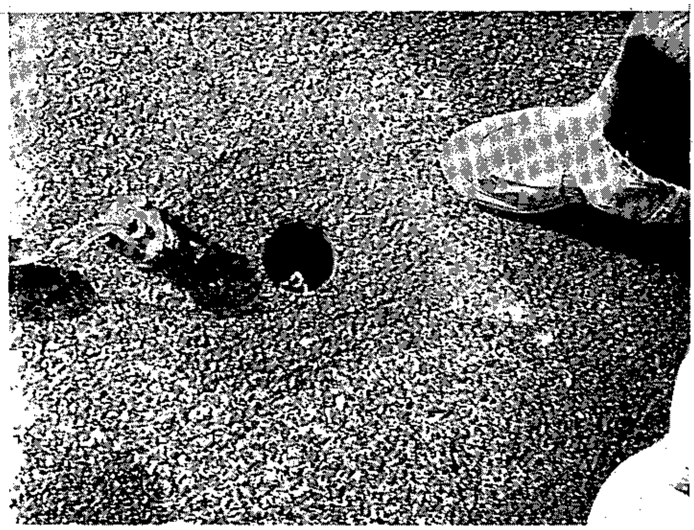


Figure 20 LVDT holder prior to placement.

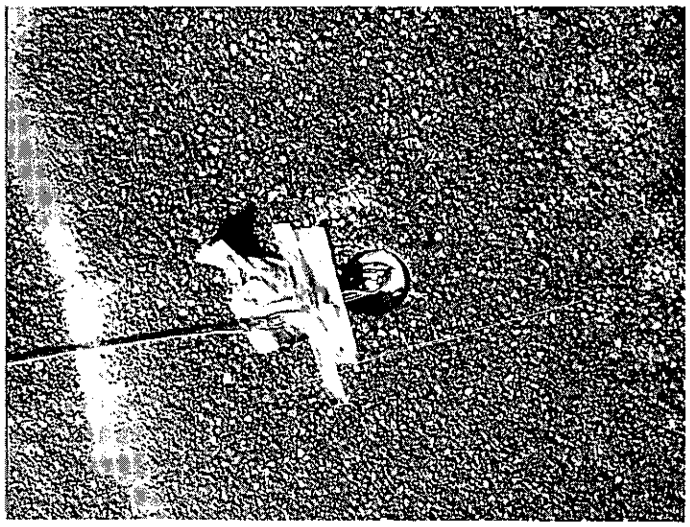


Figure 21 LVDT and holder in place.

Electronic Recording Instruments:

Figure 22 shows a graphical representation of the instruments used to record the test data. Figures 23 and 24 are interior views of the test trailer showing the instruments diagrammed in Figure 22.

In Figure 23 the instruments shown are as follows (starting from the left): Schaevitz LVDT signal conditioner; Honeywell Visicorder to record the results of the LVDT's; Brush strip recorder used to record the results of the strain gauges; Shallcross resistance decade box (on top); Hewlett Packard D.C. amplifiers; Consolidated Electrodynamics Corporation (CEC) strain gauge signal conditioner; and a Vishay signal conditioner and amplifier (partially hidden).

Figure 24 shows a close-up of the Visicorder and Brush strip recorders during an actual test. The Visicorder uses Lino-Writ 5B direct writing paper, while the Brush uses Kodak type 2022 light sensitive paper.

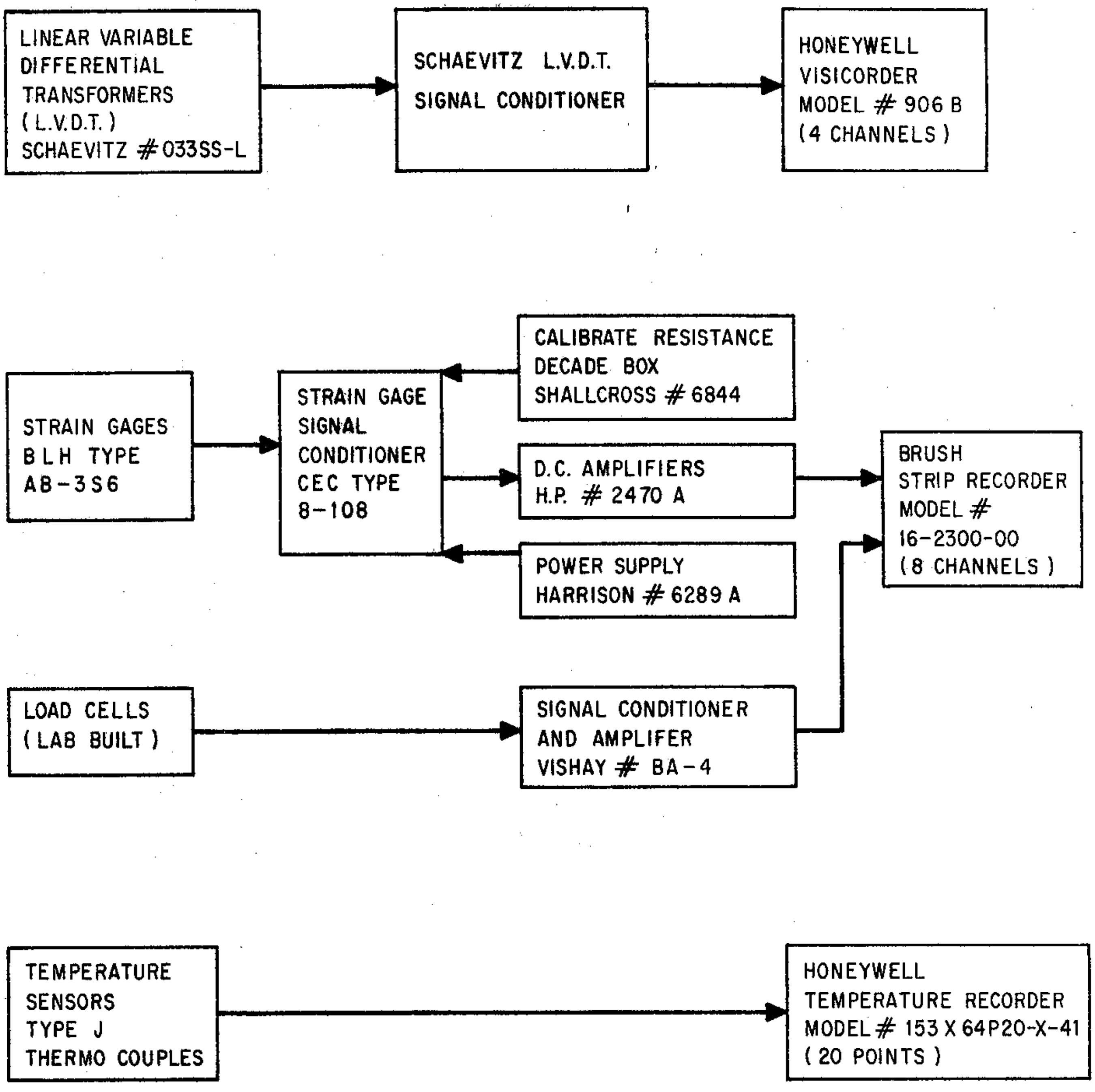
Testing Procedure

After completing the instrumentation of the pavement, testing was accomplished with a truck of known axle weight and tire pressures. The theoretical values are based on dynamic loads and hence the tests were conducted with moving trucks. The actual time of loading and geometrics of the truck's dual tires will be used for the computer determined stresses, strains and deflections.

Calibration of the instruments was performed periodically throughout the testing period to insure that the instruments were operating correctly. Due to the fact that all the testing was dynamic in nature, the possibility of temperature drift causing erroneous strain gauge data during each load application (approximately 0.5-2 sec. in duration) was ignored. However, the changes in ambient temperature between load applications were compensated for by adjusting a wheatstone bridge located in the instrument trailer prior to each pass of the test truck. This same type of testing procedure was also used at the Blythe and Willits test sites.

Figure 22

DATA ACQUISITION FOR AC PAVEMENT INSTRUMENTATION



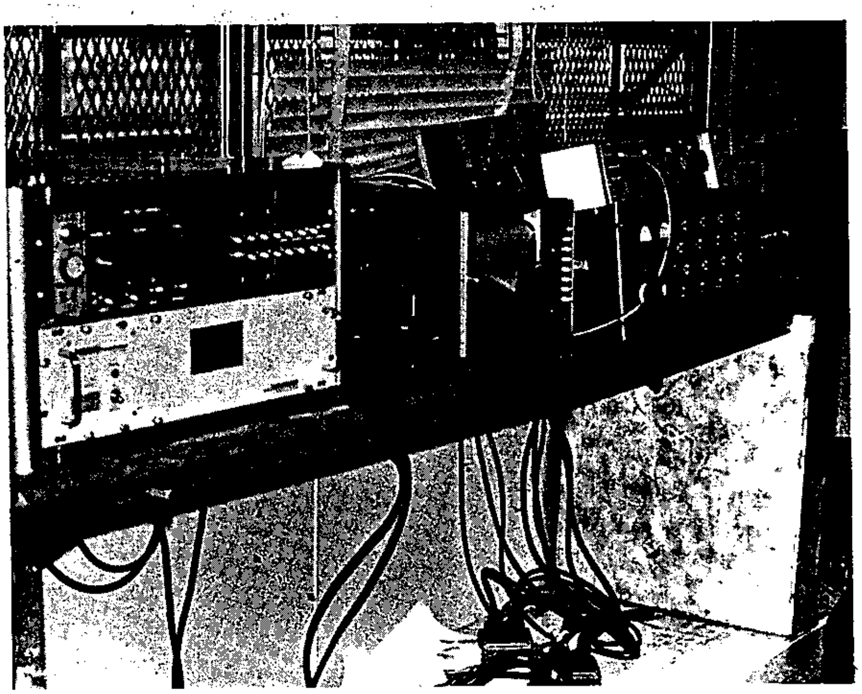


Figure 23 Electronic Equipment

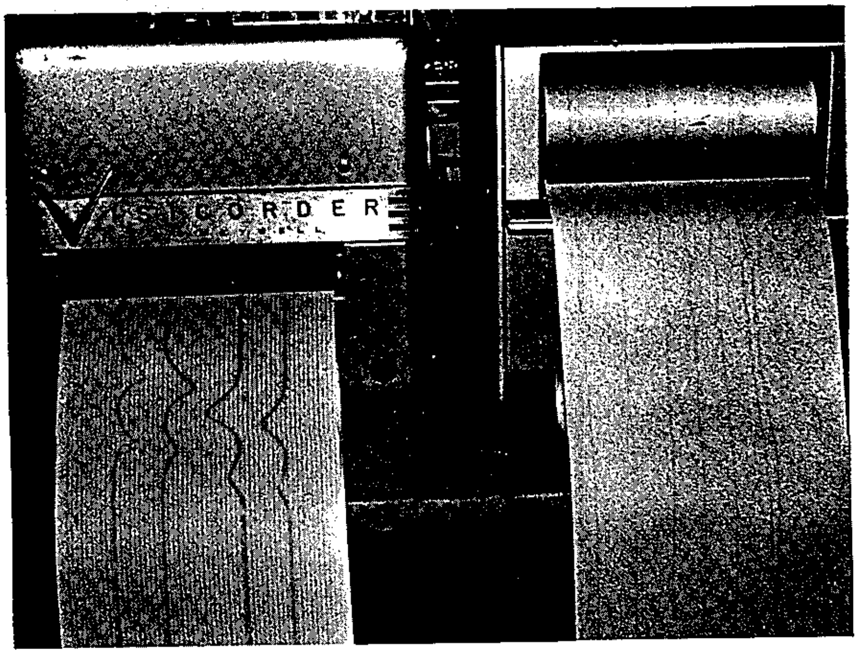


Figure 24 Visicorder and Brush strip recorders.

VI. DISCUSSION OF INSTRUMENTS AND INSTALLATION - BLYTHE

"Stress" Gauge - UC Type:

Since the Gentran pressure cells did not perform adequately in the field, a new type of pressure cell was tried. A literature search revealed that the University of California had made their own stress gauges for use in stabilized soils so five of these stress gauges were constructed as per the University of California report (8). The gauges were made out of aluminum alloy 6061-T6, with dimensions as shown in Figure 25. Two of the five gauges were installed at Blythe.

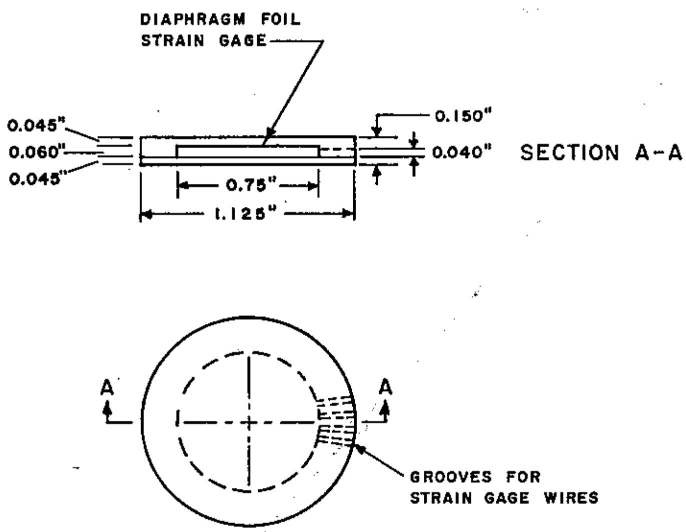
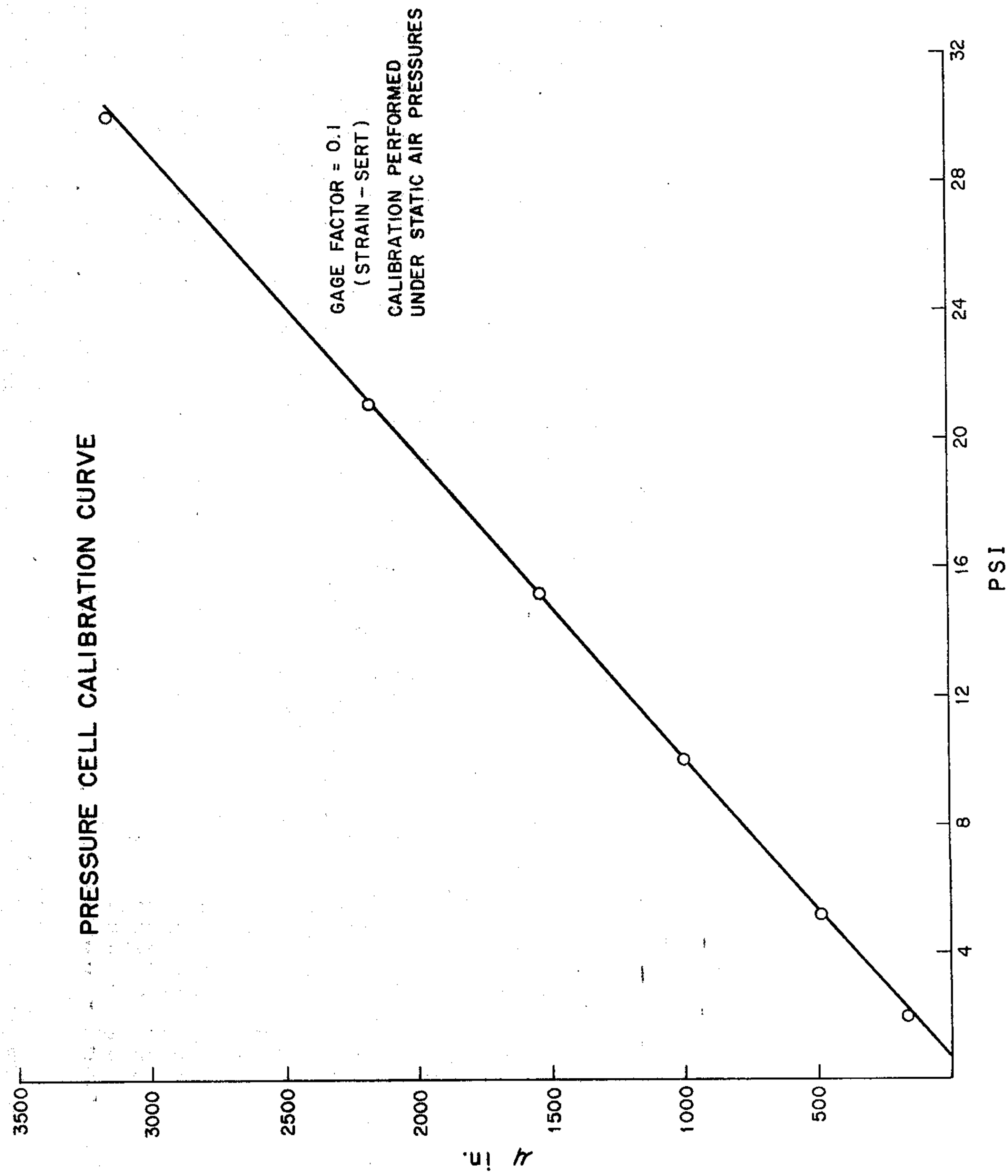


Figure 25 UC Type stress gauge.

A full bridge-in-foil type of strain gauge (BLH Catalogue number FAES-4-70-12S13) was mounted on the inside of the casing using the EPY-150 epoxy previously described.

When the gauges were calibrated it was discovered that the gauges were too insensitive to be read using the standard gauge-factor of 2.0 with a Strain-Sert instrument. In order to get adequate sensitivity, the gauge-factor had to be set to 0.1. Also, due to time limitations, the gauges were calibrated under statically applied air pressure. A typical calibration curve is shown in Figure 26. Two gauges, one at each test station, were placed at the interface of the AC and the subgrade soil. The gauges proved to be easy to install and gave measureable readings at Blythe.

Figure 26


PRESSURE CELL CALIBRATION CURVE
GAGE FACTOR = 0.1
(STRAIN - SERT)
CALIBRATION PERFORMED
UNDER STATIC AIR PRESSURES
3500
3000
2500
2000
1500
1000
500
μ in.
4
8
12
16
20
24
28
32
PSI

Strain Gauge - Sand-Asphalt Carriers:

In order to measure the strain on the underside of the AC, sand-asphalt carriers were tried. This method was recommended by A. J. G. Klomp of the Shell Laboratory in Holland (9). The carriers were approximately 4 x 7 x 1/4 inch in size. Their composition was 80 percent river sand, 20 percent filler (limestone), and 7 percent asphalt cement (85-100 penetration). Two strain gauges were epoxied to the carriers perpendicular to each other. The method of adhering the strain gauges to the carriers was exactly the same as that used when epoxying strain gauges to the asphalt concrete specimens and asphalt concrete pavement previously described (Indio). These were also done in the lab prior to actual field use.

Two different methods were used when placing the sand-asphalt carriers. One method consisted of digging out the AC after the paver passed the desired location, placing the carriers, and then covering the carriers with AC prior to the rolling operation. This procedure did not work out well as it proved to be difficult to locate the exact AC-basement soil interface. The other method used was to place the carriers at the desired location in the subgrade prior to the paver arriving at the site. The top of the carriers were placed flush with the top of the subgrade and a trench dug for the lead wires to minimize the risk of the paver tearing or picking up the wires (Fig. 27).

This method worked well. One problem encountered was that because of the high temperatures at Blythe, the carriers had a tendency to crumple when being handled. Therefore, extra care was required when handling these carriers in warm climates. Sixteen gauges were placed on sand-asphalt carriers at Blythe. Eleven were operational at the time of testing. See Figures 28 and 29 for the location of the gauges of Blythe.

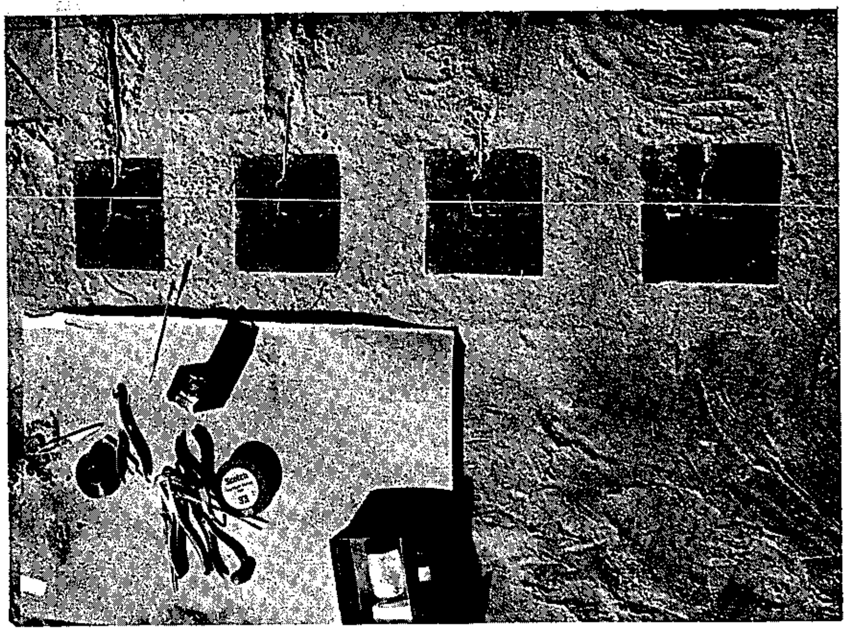


Figure 27 Sand-Asphalt Carriers with Strain Gauges.

Figure 28

BLYTHE
TEST SECTION A, INSTRUMENTATION

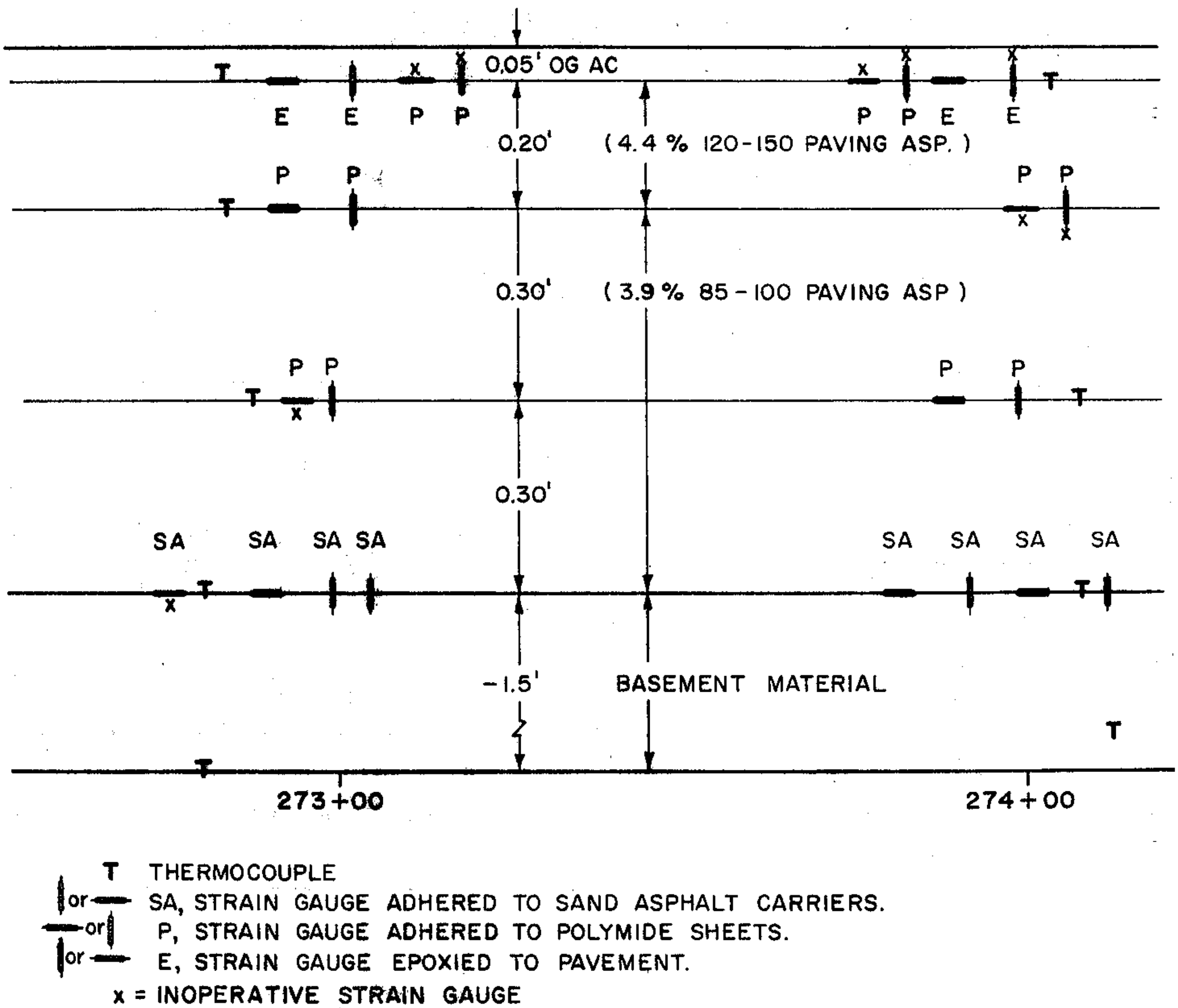
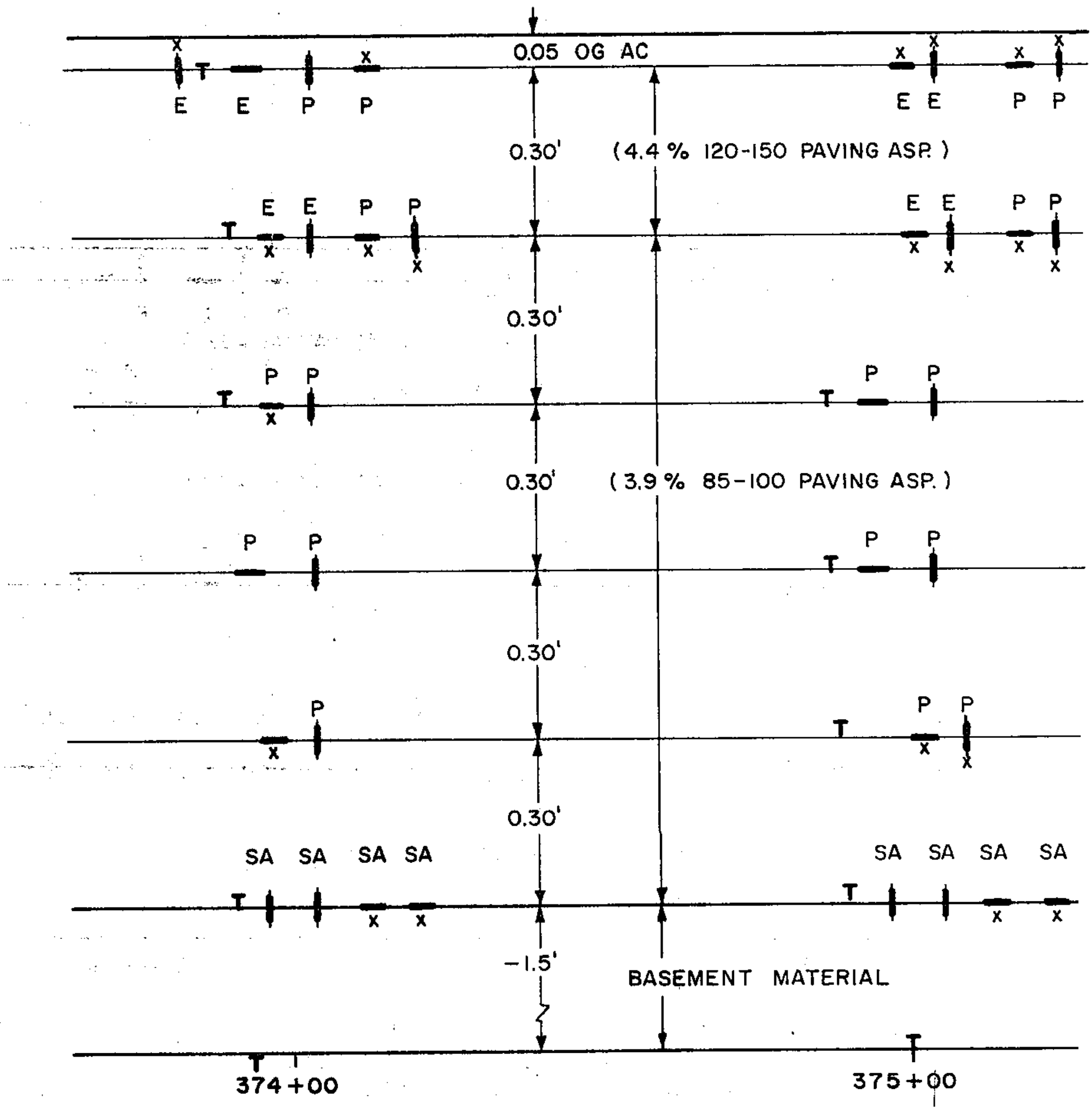


Figure 29

BLYTHE
TEST SECTION B, INSTRUMENTATION



T THERMOCOUPLE
SA, STRAIN GAUGE ADHERED TO SAND ASPHALT CARRIERS.
or P, STRAIN GAUGE ADHERED TO POLYMIDE SHEETS.
or E, STRAIN GAUGE EPOXIED TO PAVEMENT.
x = INOPERATIVE STRAIN GAUGE

Strain Gauge - Polymide Sheets:

The base course AC was placed on successive days. Consequently, there was not enough time between lifts to epoxy strain gauges to the proceeding lift. The method used to expedite the placing of the strain gauges was to attach them to 8-1/2 by 11 inch sheets of 3 mil thick DuPont Kapton (R) polymide film. Two strain gauges were adhered to each piece. The method used to adhere the strain gauges to the polymide sheets was as follows: sand blast the sheet to improve the texture for the adhesive; epoxy the strain gauges to the sheets using Micro-Measurements M-Bond 610 adhesive kit; place the sheets in an oven for about 8 hours to cure; then, after cooling, attach the lead wires to the strain gauges and cover the entire assembly with the thiokol epoxy mixture and RC-9 described earlier in this paper (Fig. 30).

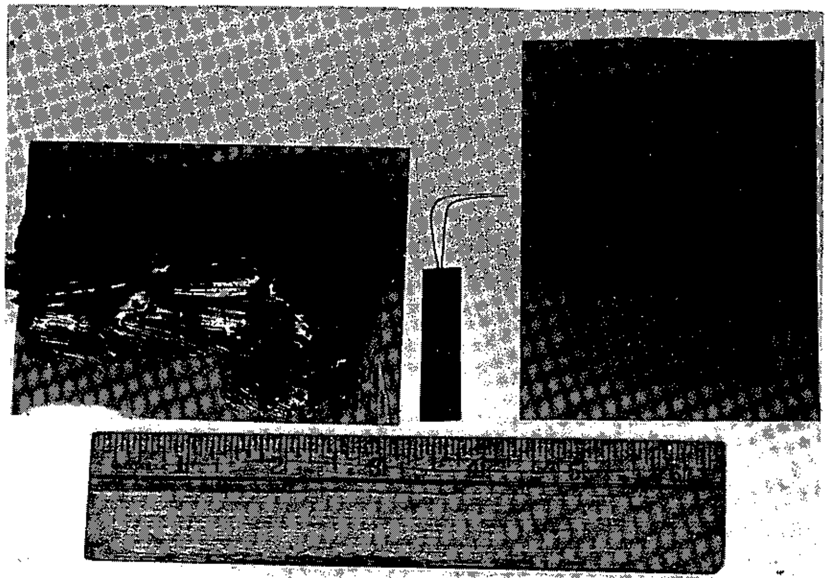


Figure 30 Polymide Sheets - Before and after placing gauges.

As all of this was done in the lab, the only field operation consisted of bonding the polymide sheet to the existing AC pavement using asphalt of the same type used in the next lift of AC. This method did not work particularly well at Blythe primarily due to the high ambient temperatures present during the installation. Even though the gauges were installed in May, the temperature during this period had an average high of about 100°F with a high of 105°F for one day of the installation period. When placing the gauges in the afternoon, the hot asphalt cement used to affix the polymide sheets to the pavement would not set up rapidly and, as a consequence, the sheet had a tendency to float out of alignment. Pavement staples were attached to the lead wires to prevent this flotation, and a weight was placed on the polymide sheet in an attempt to keep the gauges in their proper position. These methods helped keep the gauges in line until the asphalt cooled off enough to set them in place. However, the rate of failed gauges placed longitudinally to traffic was extremely high while, conversely, the failing rate for the gauges placed transversely to traffic was low. While monitoring the gauges, it was noticed that the majority of the longitudinal gauges that failed did so because of the action of the breakdown roller. One particular gauge failed on the third pass of the roller, while two other gauges failed on the second pass. It was felt this unusual situation occurred due to the heat at Blythe. It is theorized that the heat of the new AC mix and the already high temperatures of the existing AC pavement combined to cause the carriers to float on the surface. As the lead wires were stapled down, the longitudinal gauges failed as the roller passed over them and strained the connections between the gauges and the leads beyond their capacity. A total of 32 gauges on polymide sheets were placed at Blythe, but only 12 were operational at the time of testing. Figures 31 to 33 show the steps used to place the strain gauges adhered to polymide sheets to an existing layer of pavement.

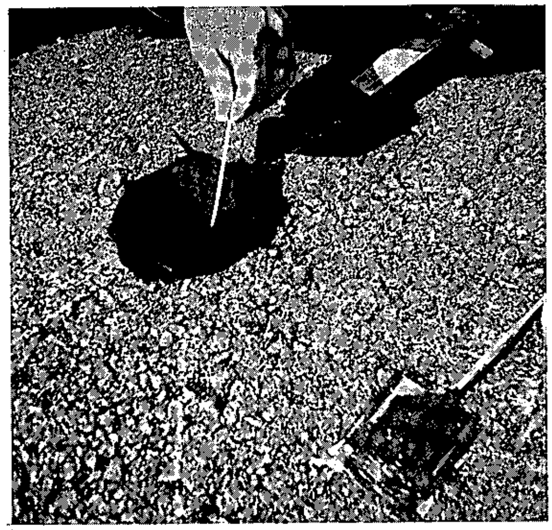


Figure 31 Step 1 - Placing the hot paving asphalt on the existing surface.

Figure 32 Step 2 - Placing the strain gauged polymide sheet to the pavement with hot paving asphalt.

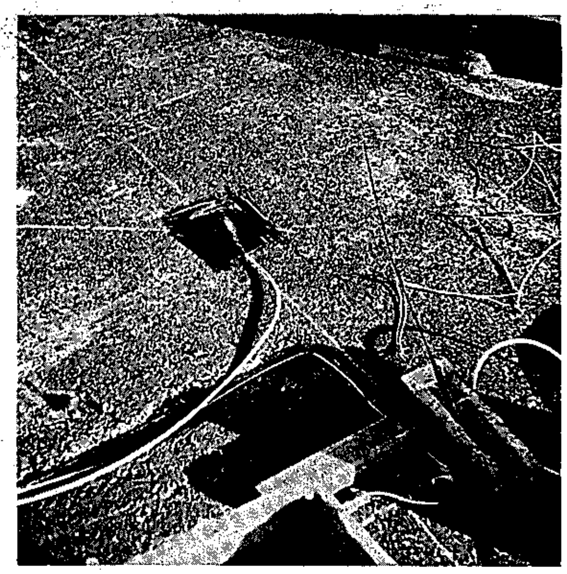


Figure 33 Step 3 - Strain gauges adhered to polymide sheet in place.

Strain Gauge - Epoxied:

For two of the lifts of AC at Blythe, the contractor's operation permitted epoxying strain gauges to the existing AC pavement adjacent to strain gauges adhered to polymide sheets. This was done to give a direct comparison between the two different methods of placing strain gauges on AC pavements. The gauges and the method used to epoxy the gauges to the pavement were exactly the same as those used at Indio. Twelve gauges were epoxied to the pavement at Blythe with five in working condition during the testing operation.

Pavement Temperature Thermocouples:

Iron-constatan thermocouples (Type J) were again used at Blythe because of the success at Indio. The thermocouples were placed at the locations shown on Figures 28 and 29 and were waterproofed using the thiokol epoxy mixture. Seven of the twenty-three thermocouples installed in the pavement were not operational after three months. Perhaps this was due to improper application of the waterproofing agent or due to the heat of the AC melting the waterproofing agent and thereby causing the thermocouple wire to rust due to subsequent moisture in the pavement. It is believed that by using copper-constatan thermocouples, the rusting problem could be avoided. Unfortunately, the proper read-out recorder for copper-constatan thermocouple wires was not available. As at Indio, a Honeywell recorder was installed in a traffic controller cabinet and used to record the thermocouple data.

Moisture Determination - Nuclear Gauge:

The method of establishing the test hole at Blythe for the nuclear probe was the same as that used at Indio. Access to the test hole was improved in that a casing with a removable cap was epoxied to the AC. Figure 34 shows the tube's final installation with the casing, cap and wrench used to remove the cap.

As stated before, the original Model P-20 nuclear gauge used for the Indio project was unable to withstand the high ambient conditions at Indio during the time of testing and, as a consequence, gave erratic and meaningless results. For Blythe, another Model P-20 was purchased from the California Department of Water Resources. This gauge gave consistent readings at each test depth (five readings were averaged), yet, for some inexplicable reason, the standard count only measured about half of what it did when the gauge was calibrated in Sacramento. When this problem has been worked out, additional testing can be made seasonally at each project.

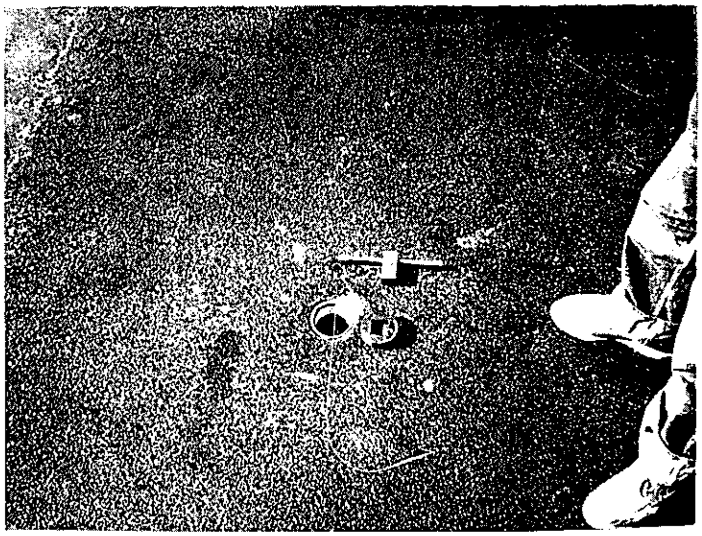


Figure 34 Depth casing and cap for nuclear probe.

Deflection Measurement -LVDT

The deflection measurement equipment and techniques used at Blythe were essentially identical to that used at Indio. The design of the device used to hold the LVDT's was modified somewhat by adding four adjustable cap screws opposite the sharpened wheels. Thus, when the cam on top of the holder was turned, the sharpened wheels were driven into the AC and the four adjustable cap screws were forced into firm contact with the opposite wall of the core hole. This provided a more stable holder than was realized at Indio. Deflection measurements were subsequently measured 1 3/4", 5 1/4", 7 3/4", and 9" below the pavement surface at Test Section A and 1 1/4", 5", 10", and 13 3/4" below the pavement surface at Test Section B.

VII. DISCUSSION OF INSTRUMENTS AND INSTALLATION - WILLITS

"Stress" Gauge - UC Type:

Just prior to the start of the paving at Willits, an attempt was made to calibrate two UC type stress gauges using a Resilient Modulus testing machine. Gauges were placed at the interface of an asphalt concrete briquette and a subgrade soil briquette from Willits (the Resilient Modulus machine uses a 4-inch ø 8-inch long sample). Unfortunately, the results proved cumbersome to obtain and the calibration obtained was erratic. Despite serious deficiencies encountered when calibrating these gauges using statically applied air pressure conditions, this calibration process was used once again. Also, the problem of the relative insensitivity of these gauges at the standard gauge-factor was still present. However, due to cost and time limitations, it was decided to use these gauges at the low gauge-factor rather than go to the added expense of having more gauges fabricated. If these gauges are to be used in future projects, a more thorough calibration procedure should be used; one in which the gauges are calibrated in the environment in which they will be placed. Also, the gauges should be made more sensitive by decreasing the thickness of the diaphragm. After it was discovered that the gauges were relatively insensitive, it was learned that in order to read pressures in the range from 0 to 20 psi (the expected magnitude in the field), a diaphragm thickness of 0.010 inch would be needed (10).

Strain Gauge - General:

At Willits, the same type of strain gauges used at the Blythe project and one additional type were used. The type of strain gauges installed at Willits were as follows:

(1) Strain gauges adhered to sand-asphalt carriers used to measure the strain on the underside of the AC.

(2) Strain gauges adhered to an existing layer of AC.

(3) Strain gauges adhered to polymide sheets.

(4) Polyester strain gauges adhered to an existing layer of AC (not used prior to Willits).

Strain Gauge - Sand-Asphalt Carriers:

The strain gauges and method of epoxying the gauges to the carriers were identical to those used at Blythe. At Willits, a slight depression was made in the subgrade and the carriers then placed in it, making the top of the carriers flush with the top of the subgrade. The paver then placed AC directly over the carriers. At Willits all of the strain gauges placed on sand-asphalt carriers were operable after the paving was completed.

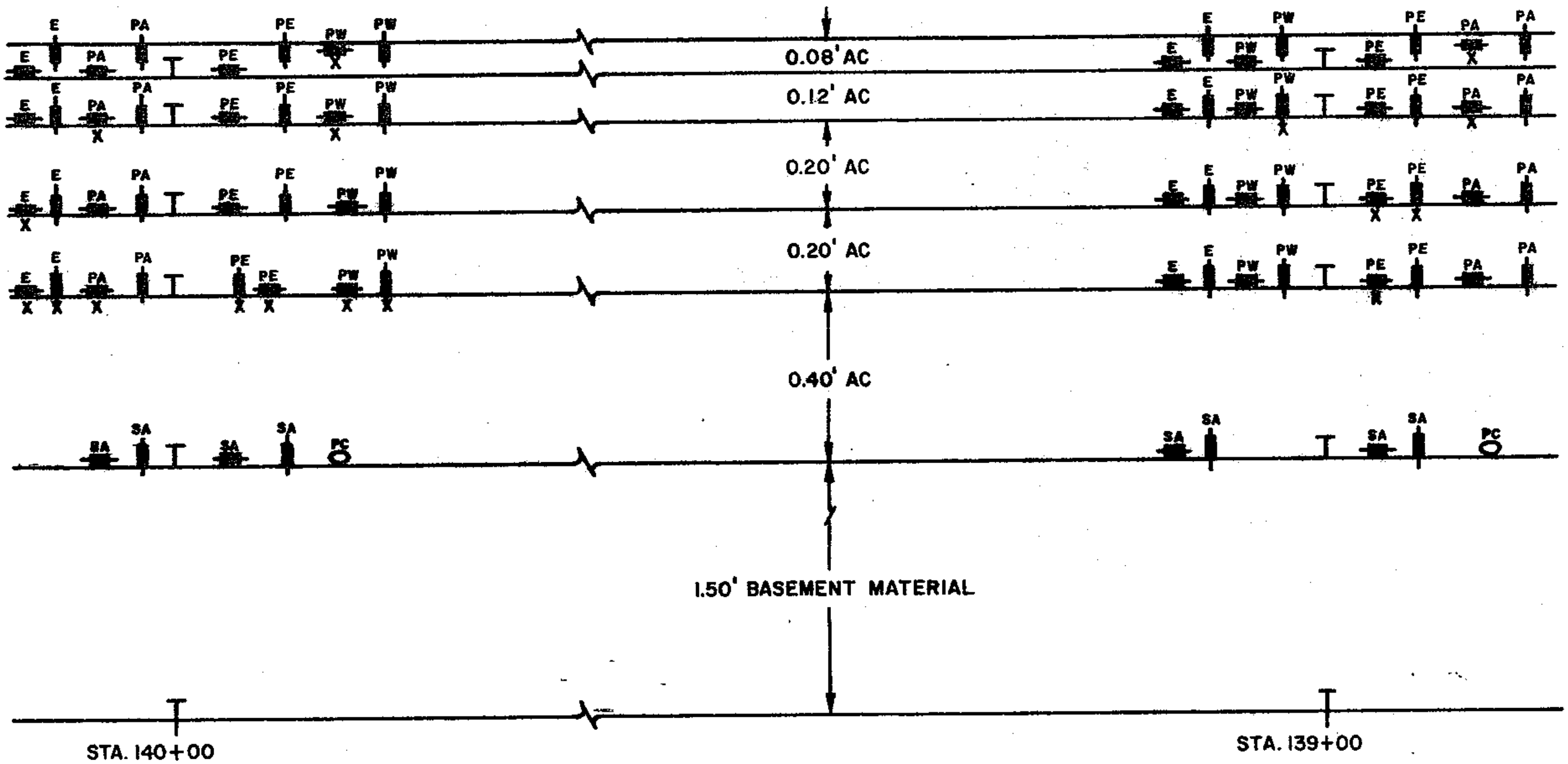
Strain Gauge - Epoxied:

The same technique as used at Indio and Blythe was used at Willits to epoxy the strain gauges to existing AC surfaces. BLH EPY-150 epoxy was used to adhere the gauges to the pavement. Fourteen out of the sixteen gauges epoxied to the pavement were operational when the pavement was tested.

Strain Gauge - Polymide Sheets:

Because of the problems encountered at the Blythe project using the polymide sheets, it was decided to use one additional method to adhere the polymide sheets to an existing AC pavement. Therefore, at Willits the polymide sheets were adhered to the pavement using 1) hot asphalt cement (as at Blythe), and 2) the in-house formulated thiokol epoxy mixture that was used as a waterproofing agent to protect the strain gauges at Indio and Blythe. Both of these methods were placed side by side to provide a comparative check on their performances. As the weather was generally cool during the installation of all the strain gauges at Willits, both methods proved to be quick and easy methods of adhering the polymide sheets to the pavement. The thiokol epoxy mixture was much easier to blend when the individual mixes were warm so the components were warmed with a butane heater at the same time the paving asphalt cement was being heated. For each of these methods, sixteen gauges (eight polymide sheets) were placed in the pavement at different depths (see Figure 35 for the complete installation at the Willits project). Both methods had about the same success ratio; twelve of the original sixteen gauges placed using asphalt cement were operable, while eleven of the gauges placed with the waterproofing agent were operable during the testing.

Figure 35



T - THERMOCOUPLE
- STRAIN GAUGE PLACED LONGITUDINALLY TO TRAFFIC
- STRAIN GAUGE PLACED TRANSVERSE TO TRAFFIC
PC - PRESSURE CELL
SA - STRAIN GAUGE ADHERED TO SAND ASPHALT CARRIERS
E - STRAIN GAUGE EPOXIED TO PAVEMENT
PA - POLYMIDE STRAIN GAUGE ADHERED W/ ASPHALT
PW - POLYMIDE STRAIN GAUGE ADHERED W/ WATERPROOFING AGENT
PE - POLYESTER STRAIN GAUGES ADHERED W/ WATERPROOFING AGENT
x - INOPERATIVE STRAIN GAUGE

WILLITS INSTRUMENTATION

Strain Gauge - Polyester:

A polyester mold strain gauge was also tried at Willits. This type of gauge was designed specifically for use in concrete research. The particular gauge used was manufactured by TML (Tokyo Sokki Kenkyujo Co.) and is distributed in the U.S. by Anderson-Lowery and Associates. The gauge was a PML-30 with a gauge length of approximately 1 1/4 inches. Its overall size was approximately 3 1/4x1/2x3/16 inches. The TML polyester mold gauge is a standard wire strain gauge hermetically sealed between two thin polyester resin blocks. The lead wires are cast as an integral part of the block, isolating the unit electrically and making it completely moisture-proof. At Willits, these gauges were attached to existing AC pavement using the thiokol epoxy waterproofing mixture.

Although the manufacturer lists the operational temperature range as -328°F to +176°F and the placement temperature of the AC mix was in excess of 200°F, only three out of sixteen gauges that were installed failed. Figure 36 shows the polyester gauge in place.

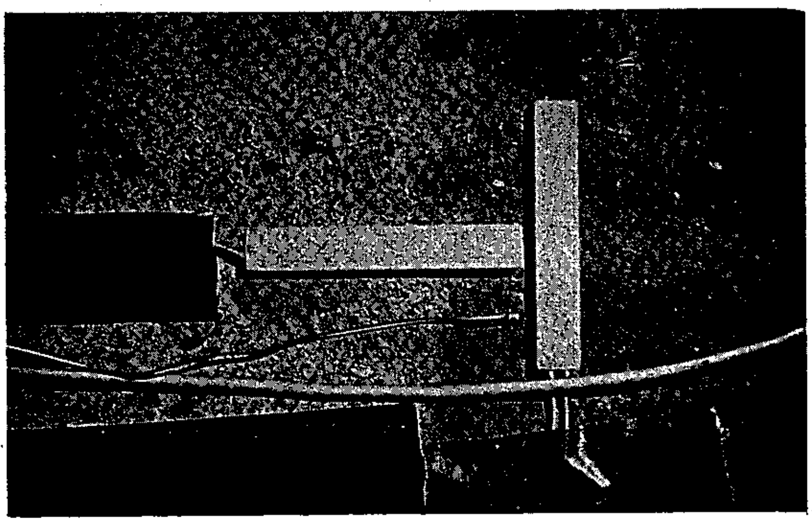


Figure 36 Polyester gauges in place on an existing AC surface.

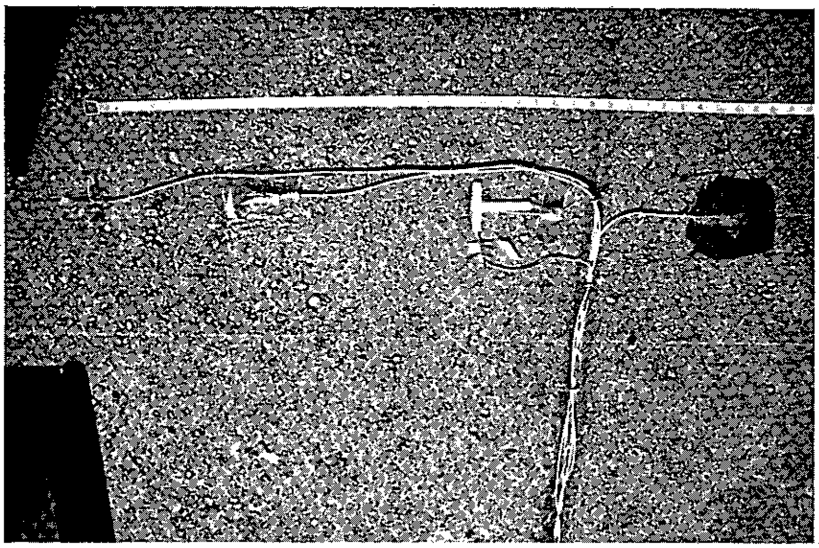


Figure 37 The four techniques used to adhere strain gauges to the pavement at Willits. From the left: (1) strain gauges adhered using the standard EPY-150 epoxy; (2) polymide sheets adhered by using thiokol epoxy mixture; (3) polyester gauges adhered used thiokol epoxy; and (4) polymide sheets adhered to the pavement using hot asphalt cement.

Pavement Temperature Thermocouples:

Again, Iron-constatan (type J) thermocouples were installed at different levels of the pavement at Willits. A Model DL-1200 Digilogger made by Austron, Inc. of Austin, Texas, was installed at Willits to record the temperature data. This machine presently has the capability to read 20 channels (one thermocouple per channel), and it can be expanded to read 50 channels. It can print out the following items:

(1) time, in hours and minutes, AM or PM
(2) date counter, single digit number 0-9
(3) the channel or thermocouple number
(4) the temperature for that particular channel in °F.

The machine can also be set to scan at 1, 2, 5, 10, 30, or 60 minute intervals. The use of this machine should greatly lessen the man-hours presently required to reduce the data from the Honeywell recorder to useable form.

Deflection Measurements - LVDT:

During the testing of the Willits test section, the same equipment and procedures used at Blythe were used to measure the deflection of the pavement 1 3/4", 4 1/2", 8", and 10" below the pavement surface.

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